Progress Report
No. 2

Temperature Modeling of Oroville Facilities
For Hydro-relicense Application

Prepared for

California Department of Water Resources
Sacramento, CA

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EXECUTIVE SUMMARY

As a part of the relicensing of the Oroville facilities, a temperature model is being developed. This report describes the update of simulations for Lake Oroville with daily intake settings and the model set up and calibrations for the Thermalito Complex. The daily shutter settings of intakes for Hyatt Plant were compiled from DWR and used in Lake Oroville simulation. The simulation with updated intake data improved the predictions of reservoir release temperatures. The model was set up to simulate the Thermalito Complex as 3 stratified reservoirs (Diversion Pool, Forebay and Afterbay) in series. The simulation results were compared to temperature profiles data collected by DWR. The simulated outflow temperatures from the Diversion Pool were compared to the temperature monitored at the power canal. The simulated Afterbay outflow temperatures were compared to the temperatures monitored at the Afterbay outlet. The results have been very reasonable.

INTRODUCTION

To support the relicensing effort for the Oroville facilities, a temperature model is being developed. The temperature model will be an integrated model that simulates temperatures of Oroville Reservoir, the Thermalito Forebay/Afterbay complex, and the Feather River from the reservoir downstream to the confluence with the Sacramento River. The integrated model will divide the Feather River below Oroville into segments as control volumes for heat budget calculations. These control volumes will be located at all compliance locations for critical habitat for fish and fish food organisms.

The integrated model will provide continuous temperature simulation of temperatures for all control volumes of the Oroville Facilities. The time step of simulation can be hourly or daily depending on the need for biological considerations.

The temperature model will be used to simulate temperatures throughout the system given a set of operational parameters such as storage, flows, releases, pump-back and diversions from the local operation model.

This is the second progress report. For completeness, this report documents all progress made to date, including those reported earlier.

FIELD VISIT

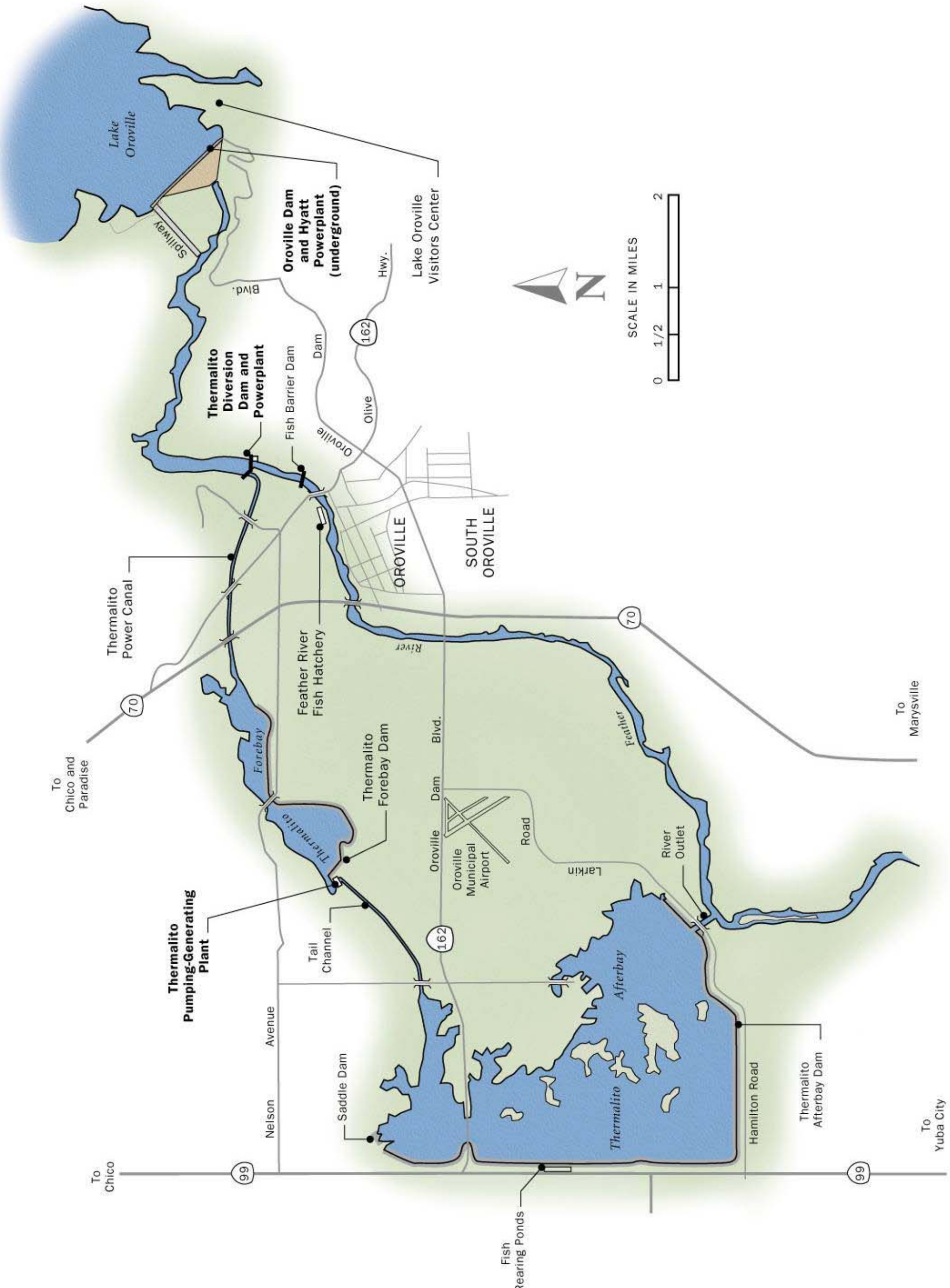
A field visit to the Oroville Facilities was made on November 21, 2002. Purposes of the visit were for us (the modelers) to familiarize ourselves with the physical settings of the facilities, to learn how the Oroville Facilities operate, and to meet with DWR staff who will supply data to the modeling team.

Curtis Creel of DWR and many members of his staff (Lori Brown, Tuan Bui, Steve Ford, Alan Ng) participated. The modeling team includes Carl Chen, Wanteng Tsai, Erich Brandstetter, and Jack Humphrey. All participants met at the Oroville Field Division. DWR provided two vans to shuttle participants to various locations. DWR also furnished a map showing various recreational facilities of the Oroville Project.

At the Hyatt Power House, we saw a video that provided an overview of the Oroville dam and its multiple intake structure. We also saw the flow release structure that by passed the turbines.

The visit led to the decision that the second meteorological tower would be placed at the radio transmission station near the Thermalito Afterbay outlet. Jerry Boles of DWR will provide much of the temperature monitoring data. He will be in the loop for all future emails related to temperature data.

Following pictures show various Oroville facilities visited.



The picture above shows a plan view of the Oroville-Thermalito Complex. There are two dams built on the Feather River. The Oroville Dam is the first large dam that impounds Lake Oroville at the upper right of the picture. The Thermalito Diversion Dam is the small dam downstream of Oroville Dam that impounds the Thermalito Diversion Pool.

Below the Oroville Dam, there is Hyatt Power Plant with pump back capability. The water from the power plant is released to the Thermalito Diversion Pool. The water from the diversion pool is diverted to the Thermalito Forebay via the Thermalito Power Canal (to the west). The water from the forebay is released through the Thermalito Power Plant to the Thermalito Afterbay. The Thermalito Power Plant also has pump back capability. The water from the afterbay is released back to the Feather River.

Below the Thermalito Diversion Dam, there is a fish barrier dam built across the Feather River. On the west bank of the Feather River, there is the Feather River Hatchery which diverts some water from the Thermalito Diversion Pool and releases it through a canal below the fish barrier dam. The canal serves as a fish ladder that attracts spawning adults to migrate to the fish hatchery for processing.

The picture above shows an aerial view of the Oroville Dam and lake. The spillway is to the left of the dam. The emergency spillway is to the right of the spillway. Flood water will flow over the emergency spillway when the reservoir's maximum capacity is exceeded.

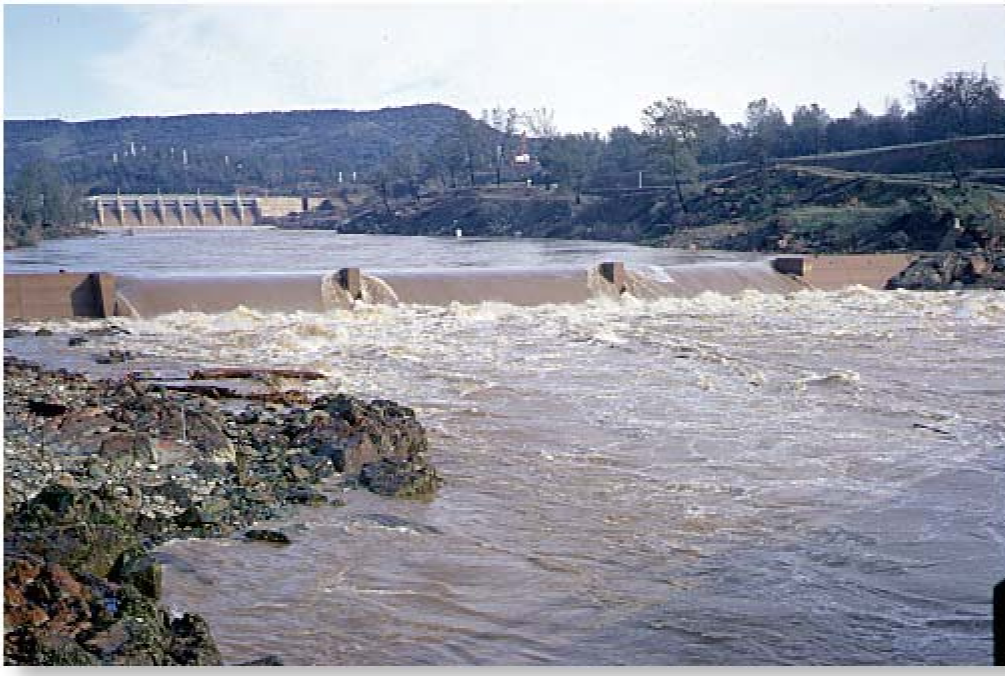
The picture above shows an aerial view of the Thermalito Diversion Dam. The diversion dam backs up the water for Thermalito Diversion Pool (to the right of the dam), which receives reservoir releases through Hyatt Power Plant. The water in the diversion pool can be released to the Feather River (to the left of the dam), diverted to the Thermalito Power Canal (on the upper left), or diverted to Feather River Hatchery (on the land between the power canal and the Feather River.   At the time of this picture, there is no direct release of water from the diversion pool to the Feather River. As shown, there is gate to release water to the Feather River without passing through the Thermalito Diversion Dam Power Plant.

The Thermalito Power Canal diverts water from the diversion pool to the Thermalito Forebay. Under normal operating conditions, water in the power canal flows from Thermalito Diversion Pool to Thermalito Forebay.   During pump back operations, the water can flow from the Forebay toward the Diversion Pool.

This is another view of the Thermalito Diversion Dam shown in the previous picture. The one-unit Thermalito Diversion Dam Power Plant is located at the far right corner of the diversion dam. The picture shows direct water releases to the Feather River without passing through the Thermalito Diversion Dam Power Plant, which was not shown in the previous picture.

The picture above shows the Thermalito Power Plant. The water upstream of the Power Plant is the Thermalito Forebay. The water downstream of the Power Plant is Thermalito Afterbay. The Thermalito Power Plant has pump back capability, in which water is released from the Forebay to the Afterbay through the power plant to generate electricity for peak hours and is pumped back from the Afterbay to the Forebay in off-peak hours.

The picture above shows an aerial view of the outlet for the Thermalito Afterbay. The Thermalito After Bay is in the back and the Feather River is in the forefront. The outflow is controlled by two gate structures. The upper gate releases water from the Afterbay to a short canal. The lower gate releases water form the short canal to the Feather River.



The picture above shows the Fish Barrier Dam below the Thermalito Diversion Dam, which can be seen in the background. The Fish Barrier Dam prevents fish from swimming upstream to the lake. Immediately downstream of the Fish Barrier Dam, there is a flow release from the Feather River Hatchery to the west bank of the Feather River. The flow guides fish to the fish ladder, which leads them to the Fish Hatchery.

TEMPERATURE MODEL OF OROVILLE LAKE

While the final product is an integrated model, we decided to proceed with model development in three parts, Oroville Lake, Thermalito Complex, and the Feather River. Such an approach enables us to show some incremental results, which will be integrated at the end. It will also provide opportunities to identify problem areas and adjust our modeling effort accordingly.

The temperature model for Oroville Lake will accept the input of meteorology, tributary inflows, inflow temperatures, reservoir releases, and pump back flows. The model will simulate lake evaporation, perform water budget calculations to predict water surface levels, perform heat budget calculations to predict temperature profiles, perform selective withdrawal calculations to predict reservoir release temperatures. The accuracy of temperature model can be evaluated by comparing model predictions to observed data.

For the initial set up of the model, the depth-area and depth-volume relationships of Oroville Lake were compiled. Figure 1 shows the depth-area relationship of Oroville Lake, and Figure 2 shows the depth-volume relationship of Oroville Lake.

The control volumes of the lake model are water layers. The model was set up by dividing the entire water body of Lake Oroville into layers, all one meter in thickness. The area of each layer was determined by the depth-area relationship shown in Figure 1. The volume of each layer was determined by the depth-volume relationship shown in Figure 2. During the model simulation, the water layer is added when the water level rises. The water layer is removed when the water level drops. The top water layer may have a thickness less than one meter.

The model set up also requires a specification of intake elevations. The Hyatt Power Plant has 13 intakes at elevations (ft) 614, 635, 654, 673, 691, 710, 729, 747, 766, 784, 803, 822, and 840. The spillway is at elevation (ft) 870. The diversion release is at elevation (ft) 552. During the model simulation, the water releases will be taken from their respective elevations.

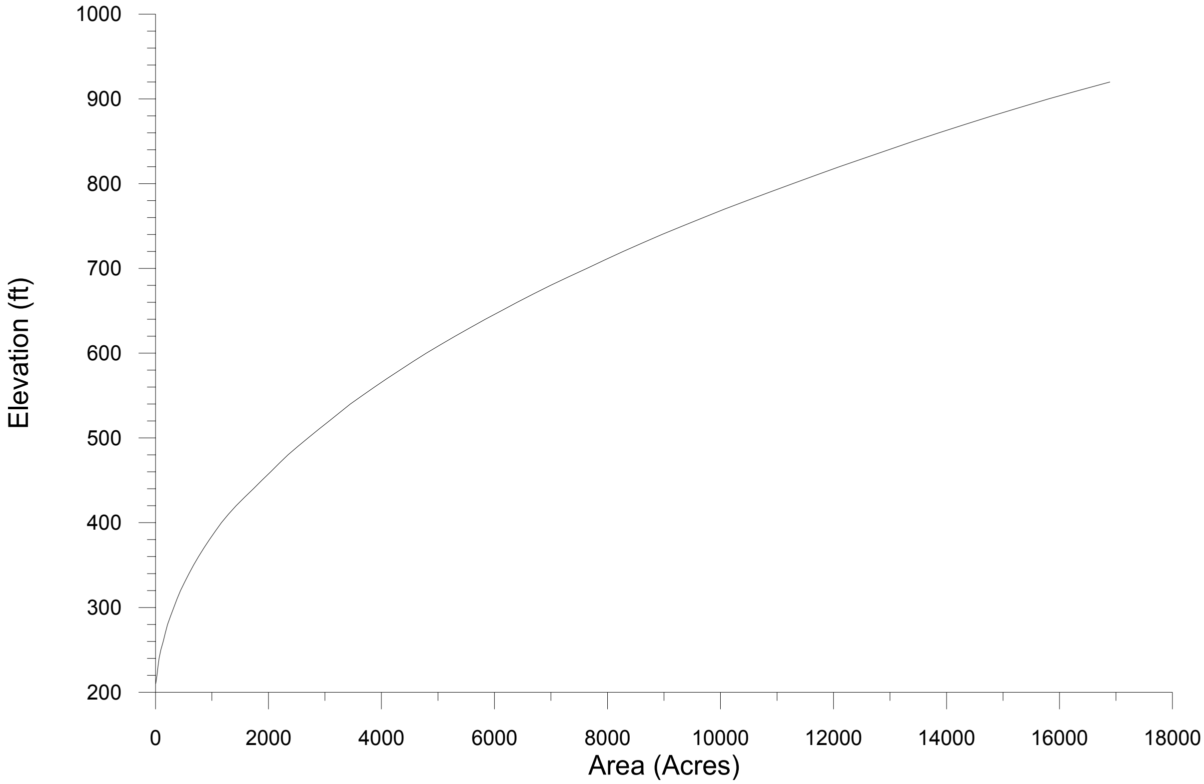


Figure 1 Depth Area Curve of Oroville Lake

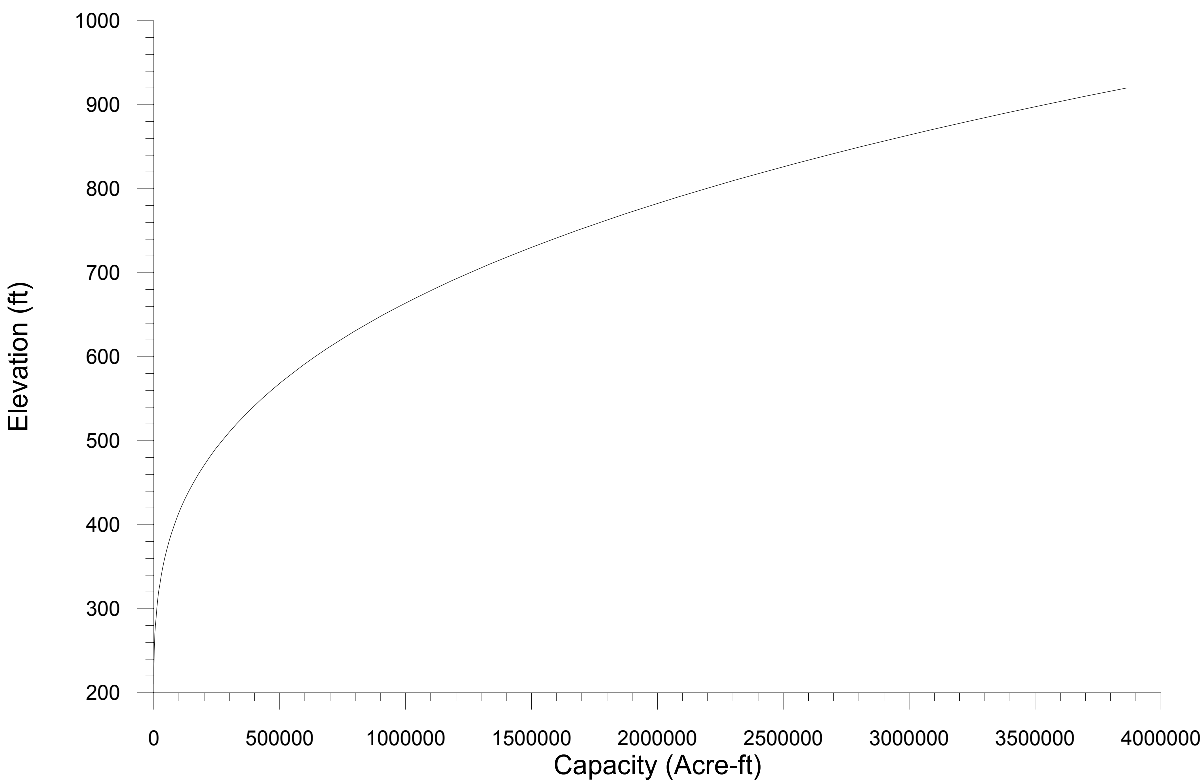


Figure 2 Depth Volume Curve of Oroville Lake

After the initial set-up, we needed to compile time varying input data. This includes meteorology, inflow, and outflow. For model predictions to be comparable to observed data, the real-time data must be used. The real-time input data has been collected by DWR for this model study.

For this initial effort, we chose to use the meteorological data of Durham Station to drive the model. Durham is a CIMIS (California Irrigation Management Information System) station that has a very long and complete data set for meteorology. Figure 3 shows the solar radiation data available from the station for the period of April to July of 2002. Figure 4 shows the wind speed data available from the station for the same period.

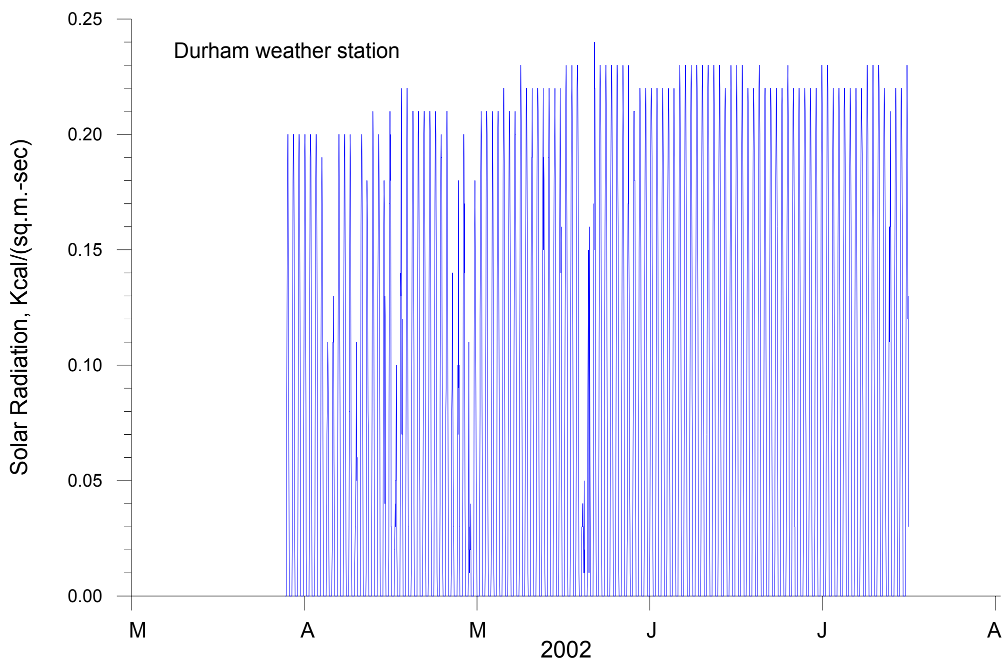


Figure 3. Solar Radiation Data at Durham Weather Station

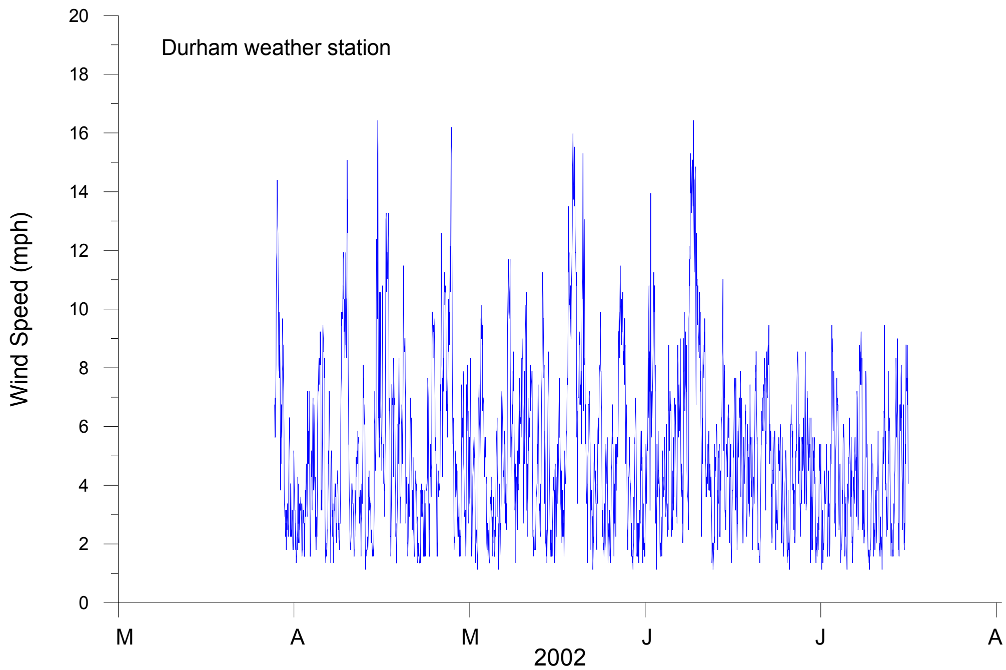


Figure 4. Wind Speed Data of Durham Weather Station

The model needs inflow data. Ideally, we would like to use the inflow data for each tributary. Unfortunately, the inflow data for each individual tributary was not readily available from the DWR data base. The red line in Figure 5 shows the total tributary inflow to Oroville Lake from April to July of 2002.

The model also needs outflow data. The blue line in Figure 5 shows the total reservoir releases through Hyatt Power Plant from April to July of 2002. To predict the temperature of flow releases, we need the outflow data for each intake to Hyatt Power Plant. For the first progress report, DWR only provided us two monthly settings of intake elevations. Based on these two settings, we estimated the daily setting for the model simulation.

We have since obtained more complete operational data from DWR. Table 1 shows the complete operational data for June 2002. The table provides the daily settings of two intake shutters. We have updated the daily input data of intake openings and re-ran the model.

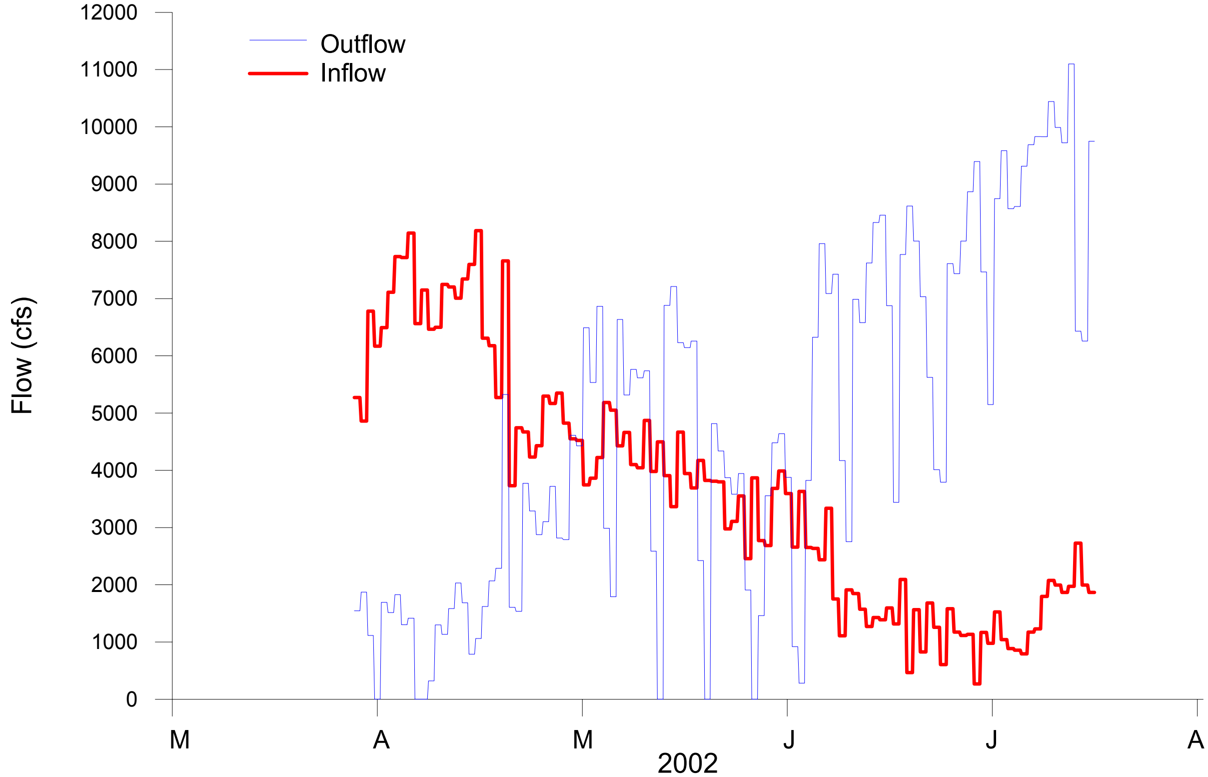


Figure 5. Inflow to and Outflow from Oroville Lake

Table 1 DWR Operational Data of Lake Oroville for June 2002.

LAKE OROVILLE INFLOW   DATE JUNE 2002

DATE	2400 ELEV	STORAGE 2639509	STOR. CHANGE	GEN A.F.	SPILL +	HYATT LEAK +	PUMP -	SHUTTER I	SHUTTER II	PAL	EVAP	A.F.	C.F.S.	FLOOD RES.
1	837.38	2,642,595	3086	2,032		59	242	7	7	28	310	5,273	2,658	900.00
2	837.87	2,648,902	6307	2,093		80	1,562	7	7	28	252	7,198	3,629	900.00
3	837.67	2,646,326	2576	7,552		33		7	7	28	222	5,259	2,651	900.00
4	837.08	2,638,738	7588	12,515				7	7	28	266	5,221	2,632	900.00
5	836.20	2,627,447	11291	15,754				7	7	28	339	4,830	2,435	900.00
6	835.59	2,619,639	7808	14,029		6		7	7	28	361	6,616	3,336	900.00
7	834.68	2,608,023	11616	14,696		30		7	7	28	337	3,475	1,752	900.00
8	834.18	2,601,656	6367	8,243		19		7	7	28	278	2,201	1,110	900.00
9	834.01	2,599,494	2162	5,431		80		7	7	28	409	3,786	1,909	900.00
10	833.18	2,588,954	10540	13,827		20		7	7	28	328	3,663	1,847	900.00
11	832.36	2,578,571	10383	13,021		6		7	7	28	444	3,116	1,571	900.00
12	831.33	2,565,570	13001	15,093		23		7	7	28	377	2,520	1,270	900.00
13	830.22	2,551,611	13959	16,489				8	8	28	274	2,832	1,428	900.00
14	829.08	2,537,329	14282	16,742		6		8	8	28	259	2,753	1,388	900.00
15	828.22	2,526,593	10736	13,610		20		8	8	28	244	3,166	1,596	900.00

16	827.86	2,522,108	4485	6,794				8	8	28	272	2,609	1,315	900.00
17	826.93	2,510,548	11560	15,381		6		8	8	28	294	4,149	2,092	900.00
18	825.60	2,494,080	16468	17,059		26		8	8	28	278	923	465	900.00
19	824.54	2,481,010	13070	15,848				8	7	28	297	3,103	1,564	900.00
20	823.51	2,468,356	12654	13,190				7	7	28	346	910	459	900.00
21	822.85	2,460,271	8085	11,124		3		7	7	28	267	3,337	1,682	900.00
22	822.38	2,454,525	5746	7,928		62		7	7	28	218	2,490	1,255	900.00
23	821.84	2,447,935	6590	7,490		48		7	7	28	224	1,200	605	900.00
24	820.84	2,435,765	12170	15,064		29		7	7	28	182	3,133	1,580	900.00
25	819.79	2,423,032	12733	14,716		9		7	7	28	307	2,327	1,173	900.00
26	818.63	2,409,028	14004	15,847		32		7	7	28	306	2,209	1,114	900.00
27	817.33	2,393,400	15628	17,552		20		7	7	28	276	2,248	1,133	900.00
28	815.79	2,374,978	18422	18,602				7	7	28	317	525	265	900.00
29	814.72	2,362,237	12741	14,777				7	7	28	247	2,311	1,165	900.00
30	814.00	2,353,690	8547	10,177		4		7	7	28	273	1,935	976	900.00
31														
TOTAL												95,318	48,055	
MAX	837.87												3,629	
MIN	814.00													

To run the model, we also needed the flow for pump back operations. In the first progress report, we used the pump back data reported in the USGS gaging station. The pump back data has also been updated with the complete operational data provided by DWR.

Monitoring stations were installed to measure the temperatures of tributary inflows to Oroville Lake. Figure 6 shows the inflow temperatures for 3 tributaries. The average temperatures of the 3 tributaries (red line) are assumed applicable to the total daily inflow to the reservoir.

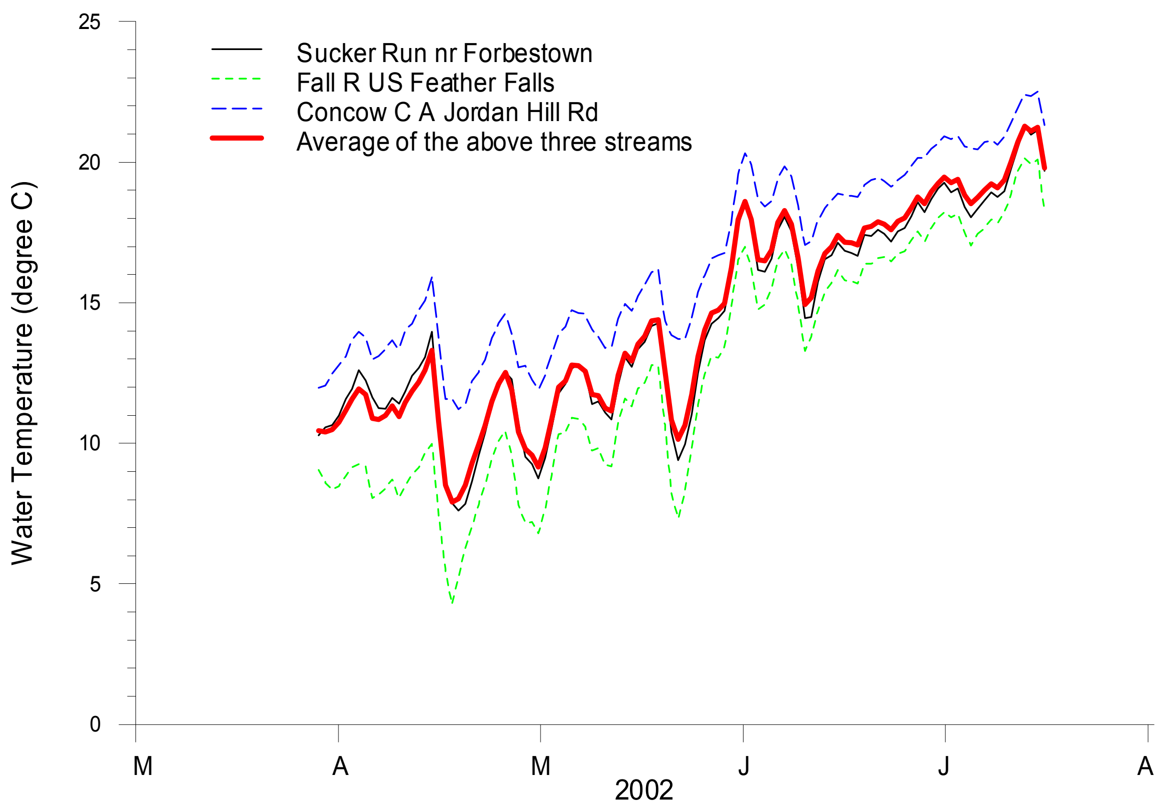


Figure 6. Temperatures of Tributary Inflows to Oroville Lake

For temperatures of pump back water, the integrated model will automatically calculate them as a part of the simulation. For now, we assume their values for input to the model.

The updated input data described above was fed to the model, which performed the simulation with an hourly time step. For each hourly time step, the daily flow data was evenly divided into 24 hourly values. The pump back flows were assumed to occur only during off-peak hours on week days and all hours on the weekends.

Figures 7 through 13 compare the simulated and observed values of various parameters. The model appears to have made accurate predictions of various parameters, for which there is observed data. The data includes lake surface elevations, cumulative lake surface evaporation and the progression of thermal stratifications from spring to summer.

It is interesting to note that the observed temperature profiles show some patterns between elevations 650 feet and 800 feet. These patterns, which appear to be created by the withdrawal of water by intakes, are simulated by the model.

Based on these results, it is concluded that the 1D vertical temperature model may be adequate for simulating the cold water storage and the temperature of reservoir releases, which affect the temperatures downstream of Thermalito complex and Feather River. Since the primary emphasis of environmental analysis is on the downstream section of the Oroville facilities instead of the reservoir itself, the decision to use 1D model is justified.

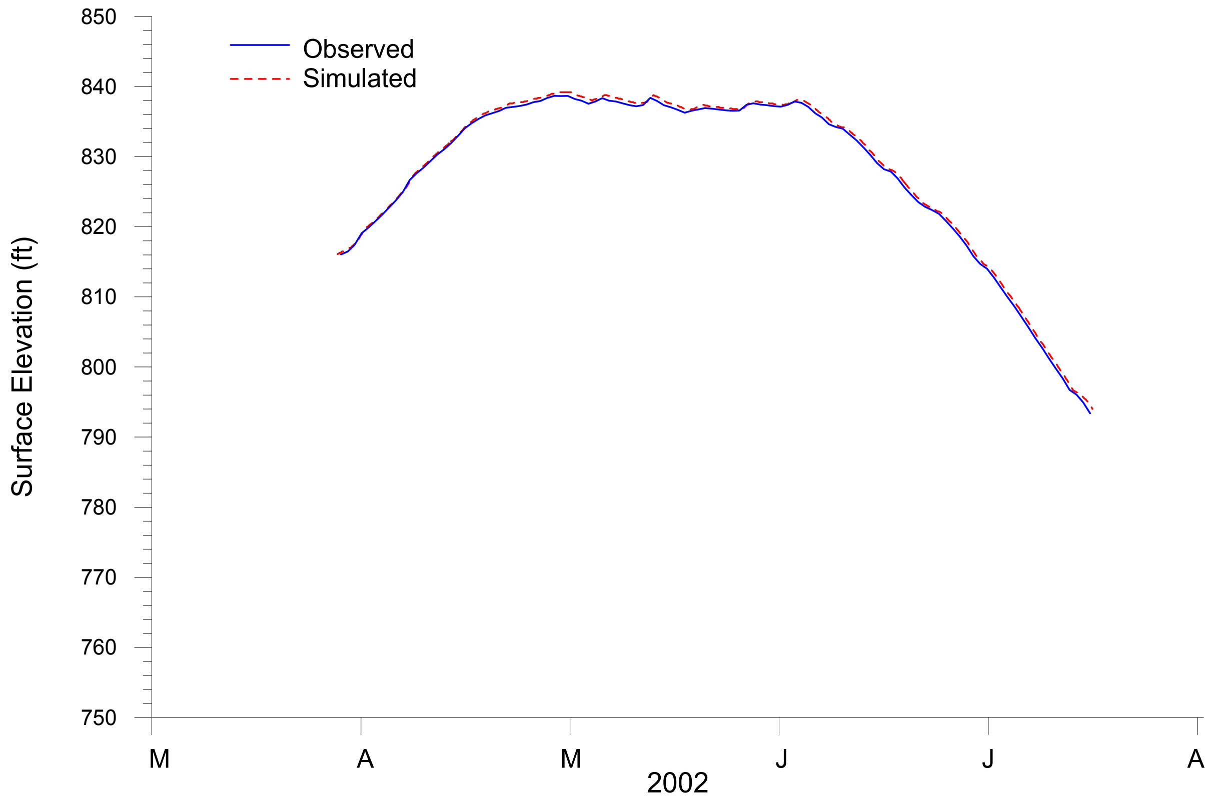


Figure 7 Predicted and Measured Lake Surface Elevation of Oroville Lake

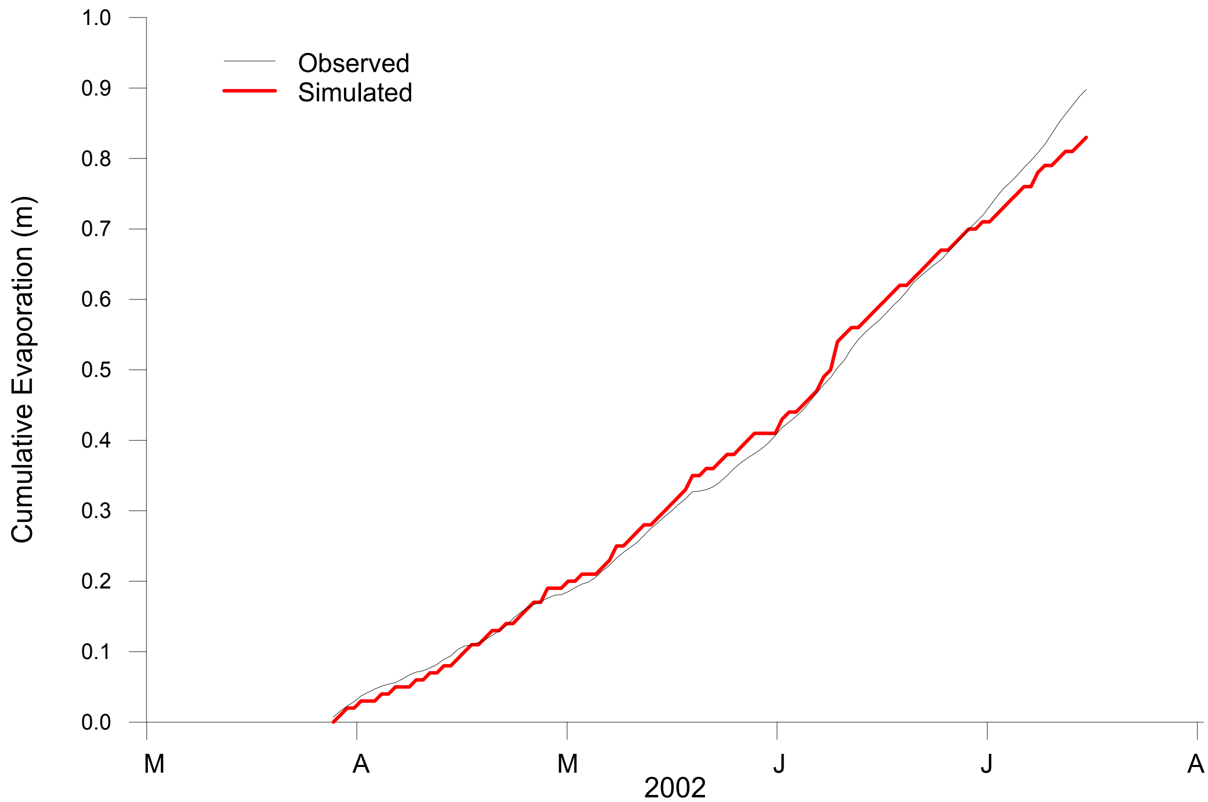


Figure 8 Simulated and Observed Evaporation for Oroville Lake

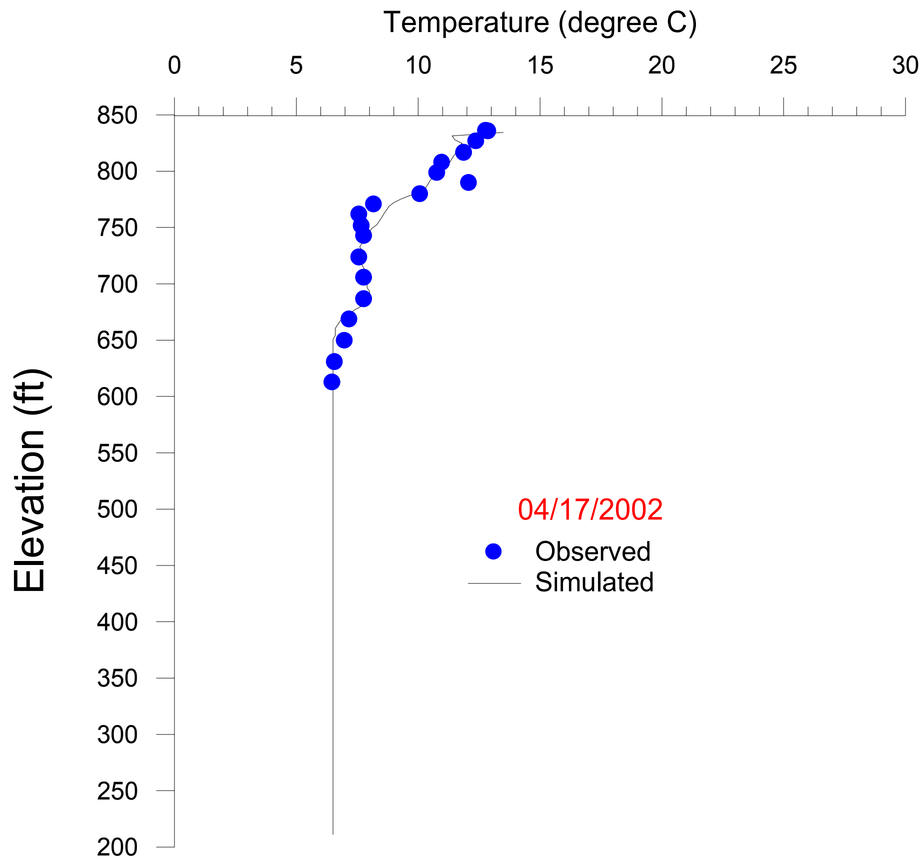


Figure 9 Simulated and Observed Temperature Profile of Oroville Lake on 04/17/2002

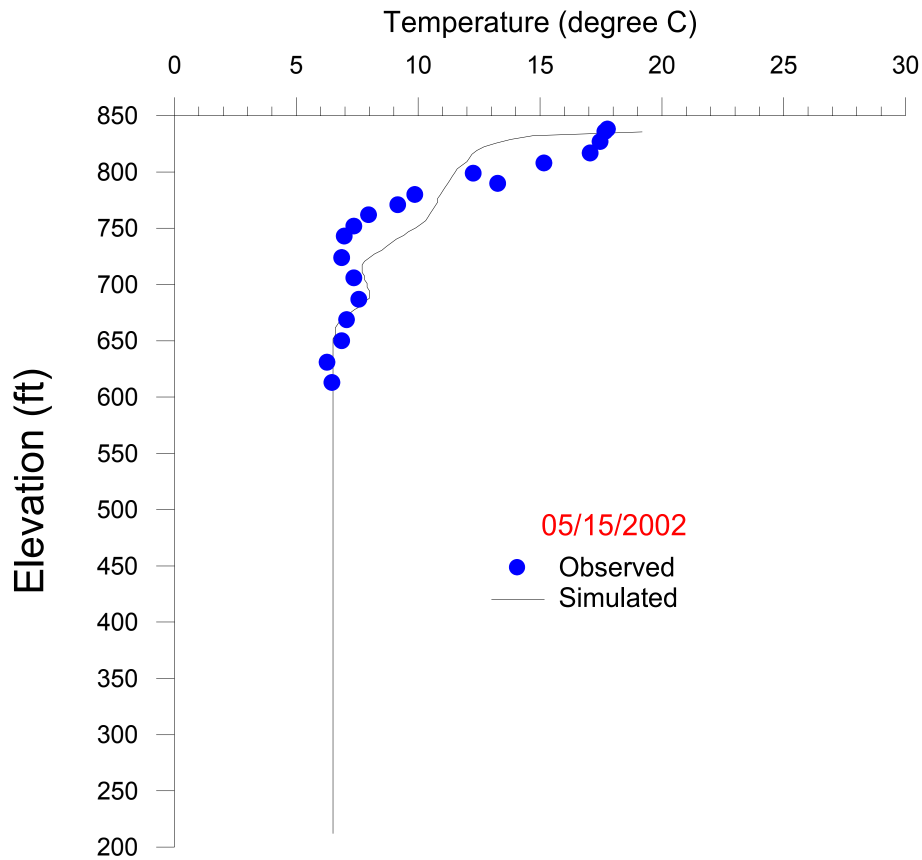


Figure 10 Simulated and Observed Temperature Profile of Oroville Lake on 05/15/2002

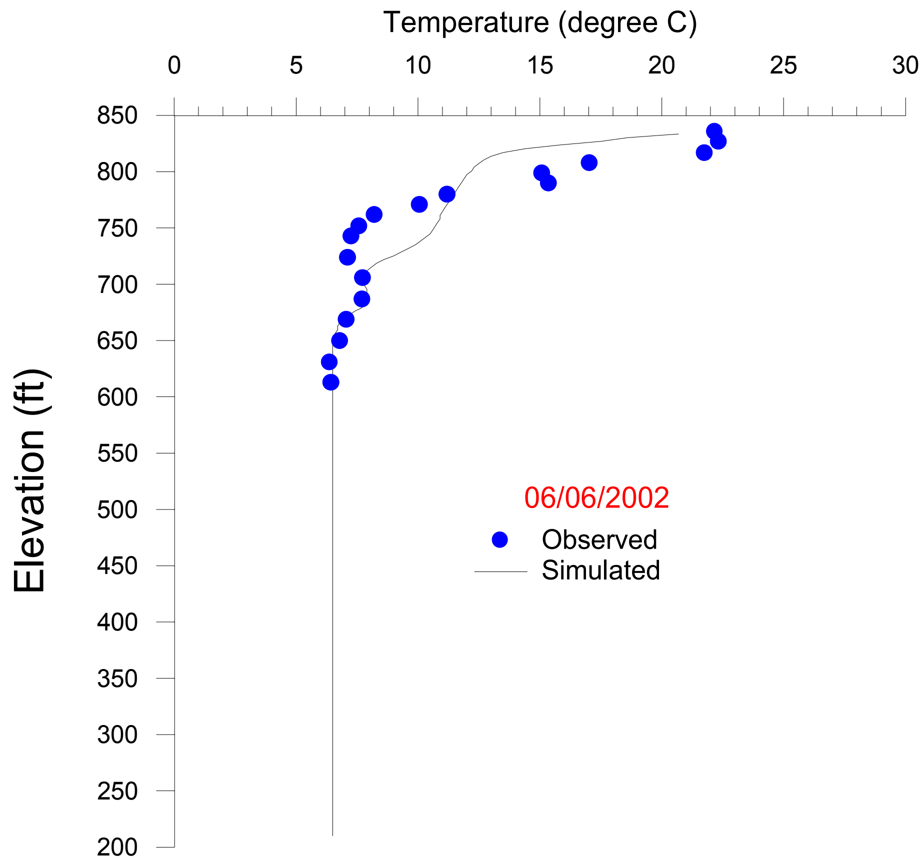


Figure 11 Simulated and Observed Temperature Profile of Oroville Lake on 06/06/2002

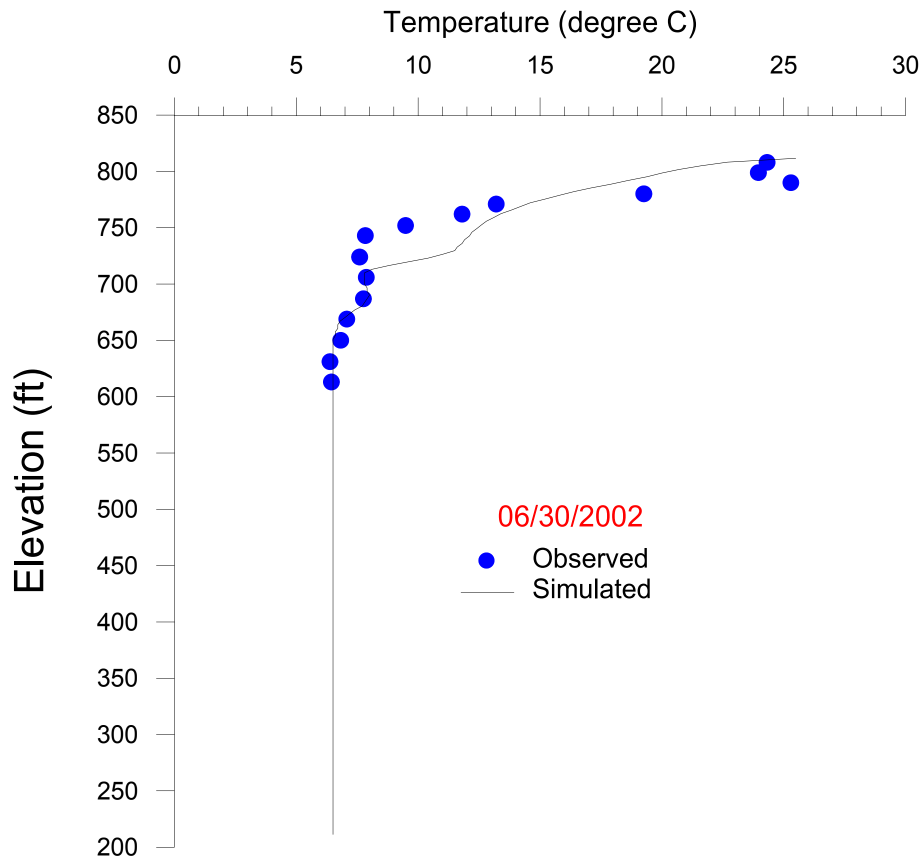


Figure 12 Simulated and Observed Temperature Profile of Oroville Lake on 06/30/2002

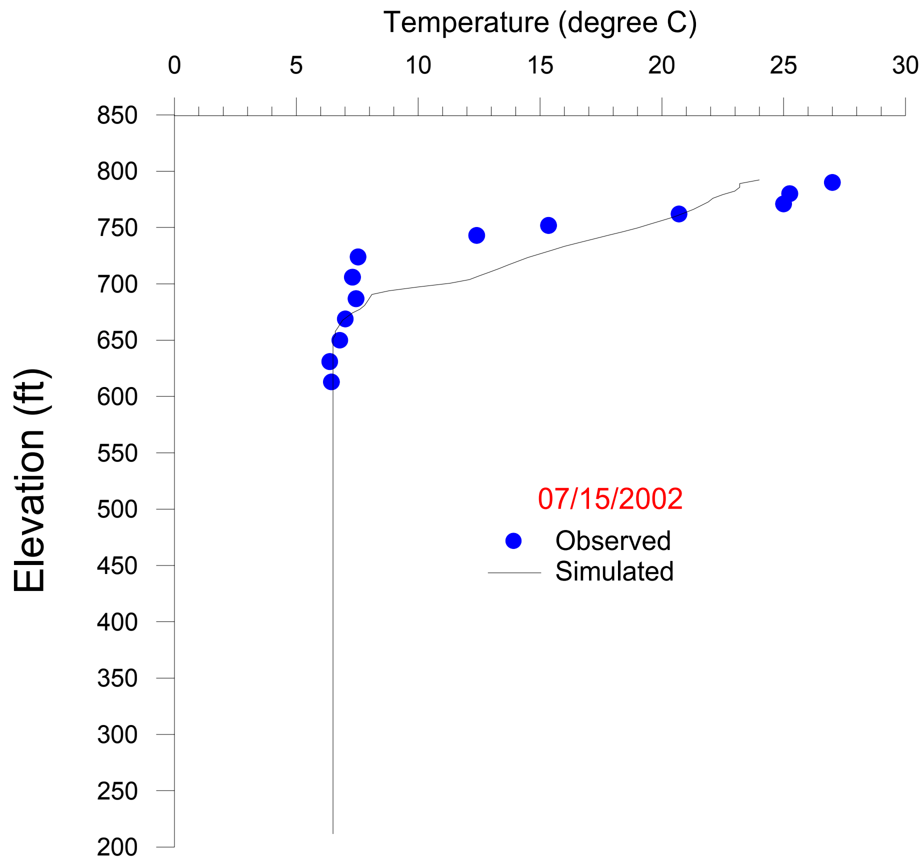


Figure 13 Simulated and Observed Temperature Profile of Oroville Lake on 07/15/2002

Figure 14 compares the simulated outflow temperatures from Hyatt Power Plant and the recorded temperatures of water in the tail race. The predicted temperatures are based on the daily intake shutter setting data. The outflow temperatures were raised 0.3 degree Celsius to account for the heat gain when passing through the turbines.

The simulated temperatures of flow releases are colder than the recorded temperatures in the months of April and May. The simulated temperatures for July match the observed data reasonably well.

We investigated the reasons for the discrepancy of model prediction. We found that the large under-predictions occurred in April and May 2002 when the flow releases were very small (Figure 5). The under-predictions did not occur in July when the flow releases were high. We suspected that the water from the Thermalito Diversion Pool flowed back to the tail race tunnel when the flow releases were low. Thus, the recorded temperatures for the tail race do not represent the temperatures of the water releases simulated by the model.

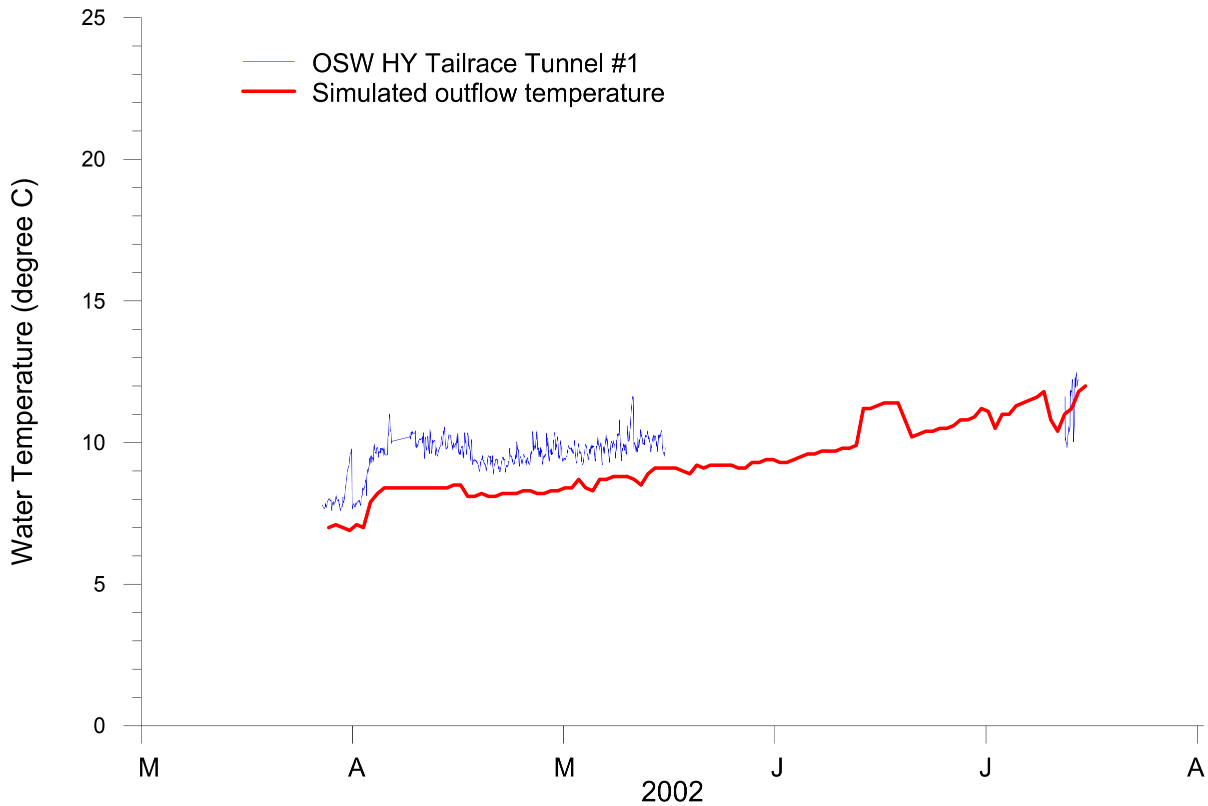


Figure 14 Simulated and Observed Outflow Temperatures of Oroville Lake

TEMPERATURE DATA OF THE THERMALITO COMPLEX

The Thermalito Complex includes the Diversion Pool, Power Canal, Forebay, and Afterbay. The surface area of the Diversion Pool is long and narrow. The Forebay and Afterbay have large round surface areas.

Intuitively, one can imagine that both the Forebay and Afterbay may be stratified due to their large surface areas to absorb heat and their large water bodies to prolong residence time. So, our initial plan was to model the Afterbay as a stratified reservoir and if necessary the Forebay as well.

Before we proceeded with model development, we compiled the data for the temperature profiles from DWR. Figures 15 through 19 show the temperature profiles measured at various locations of the Thermalito Complex at various times during calendar year 2002.

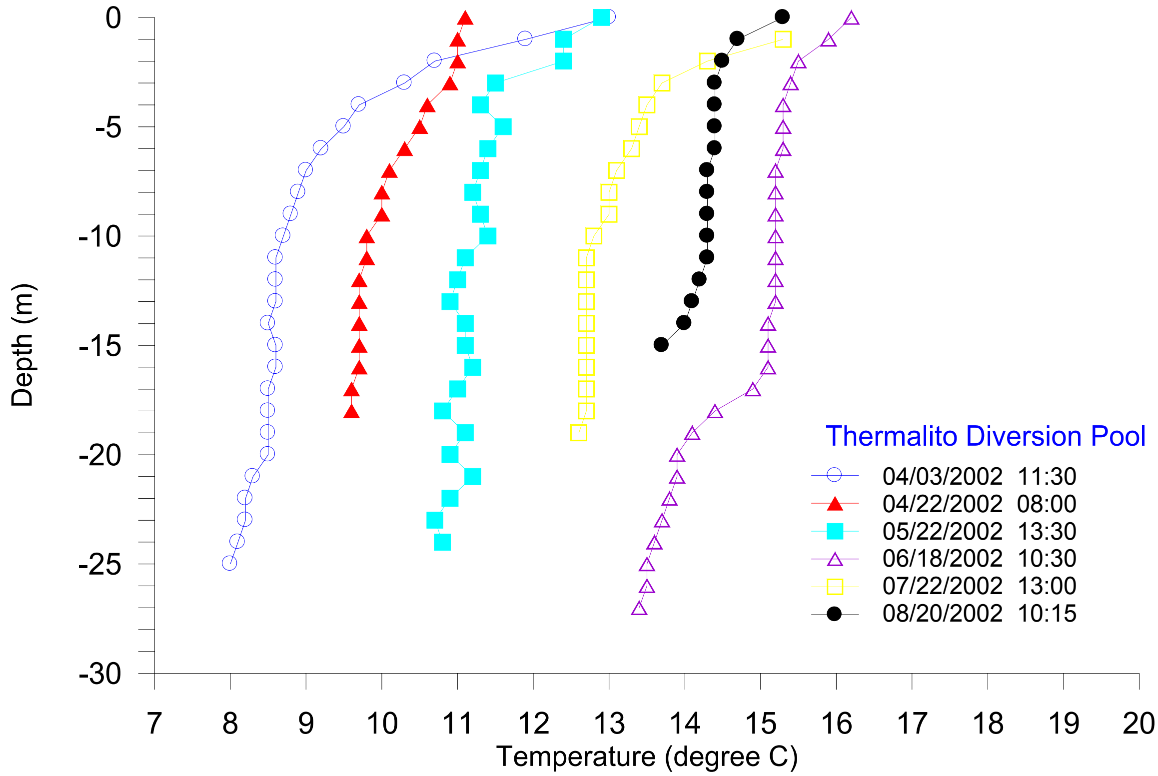


Figure 15 Temperature Profiles of Thermalito Diversion Pool

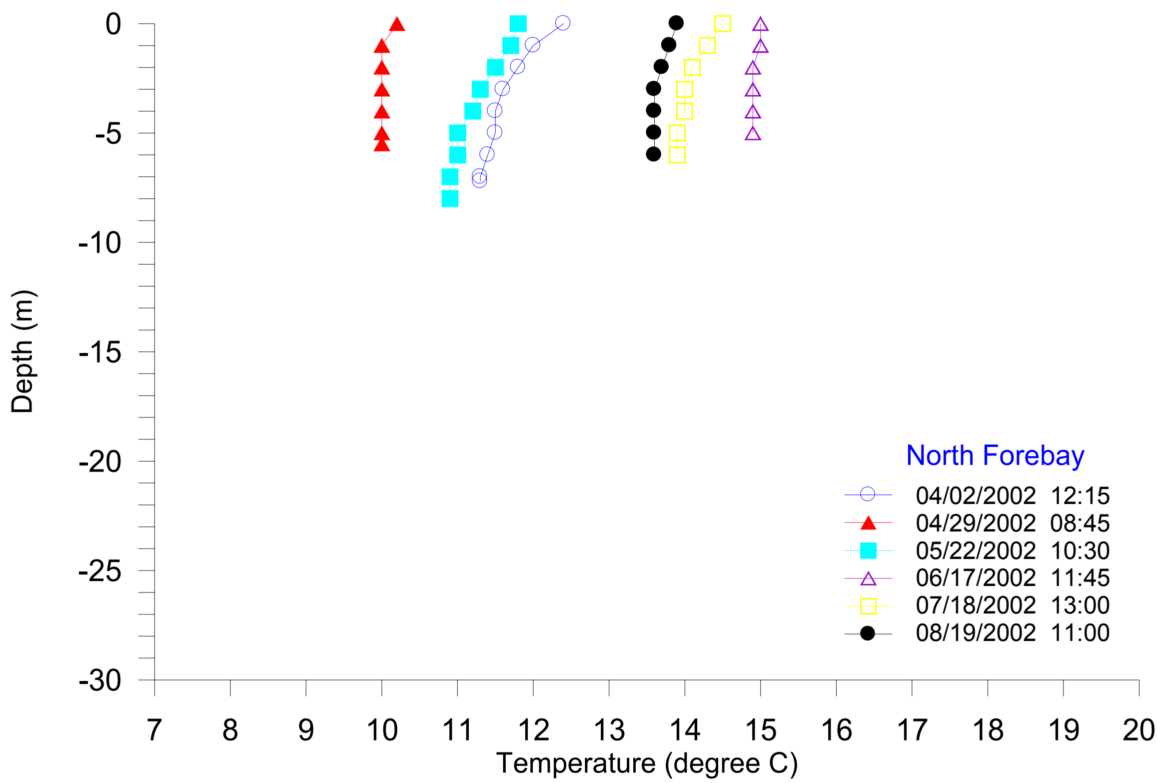


Figure 16 Temperature Profiles of North Thermalito Forebay

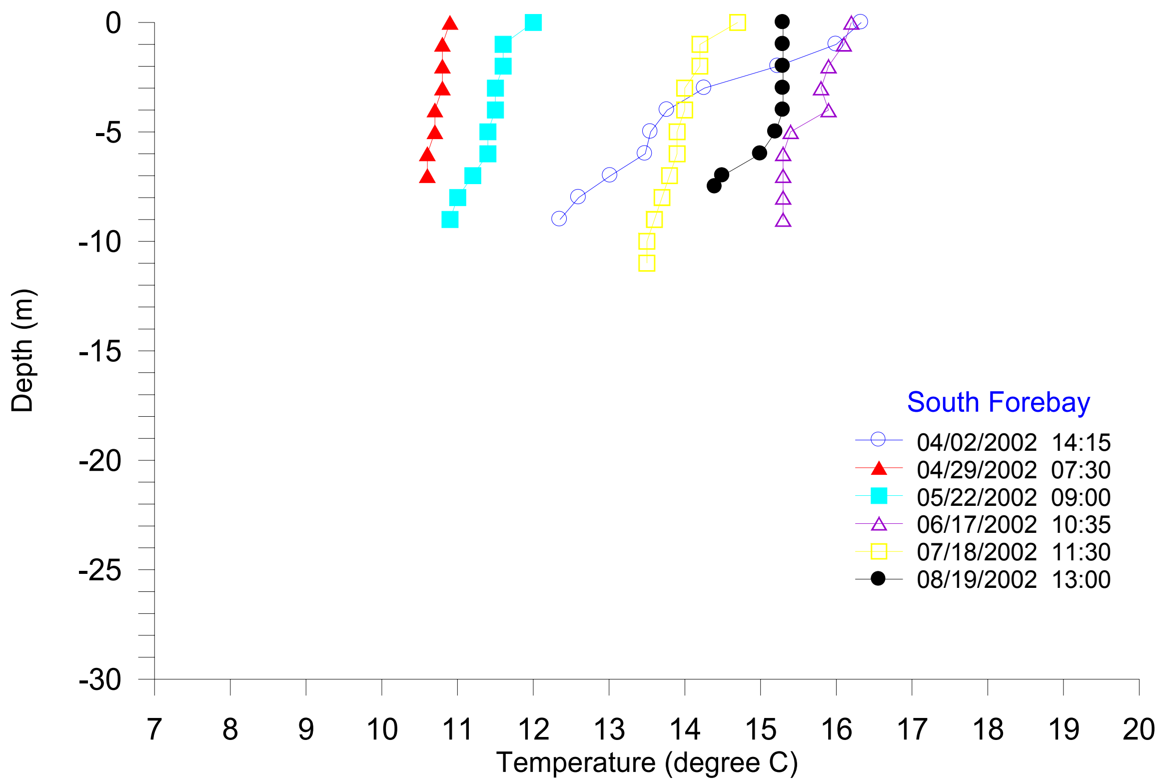


Figure 17 Temperature Profiles of Thermalito South Forebay

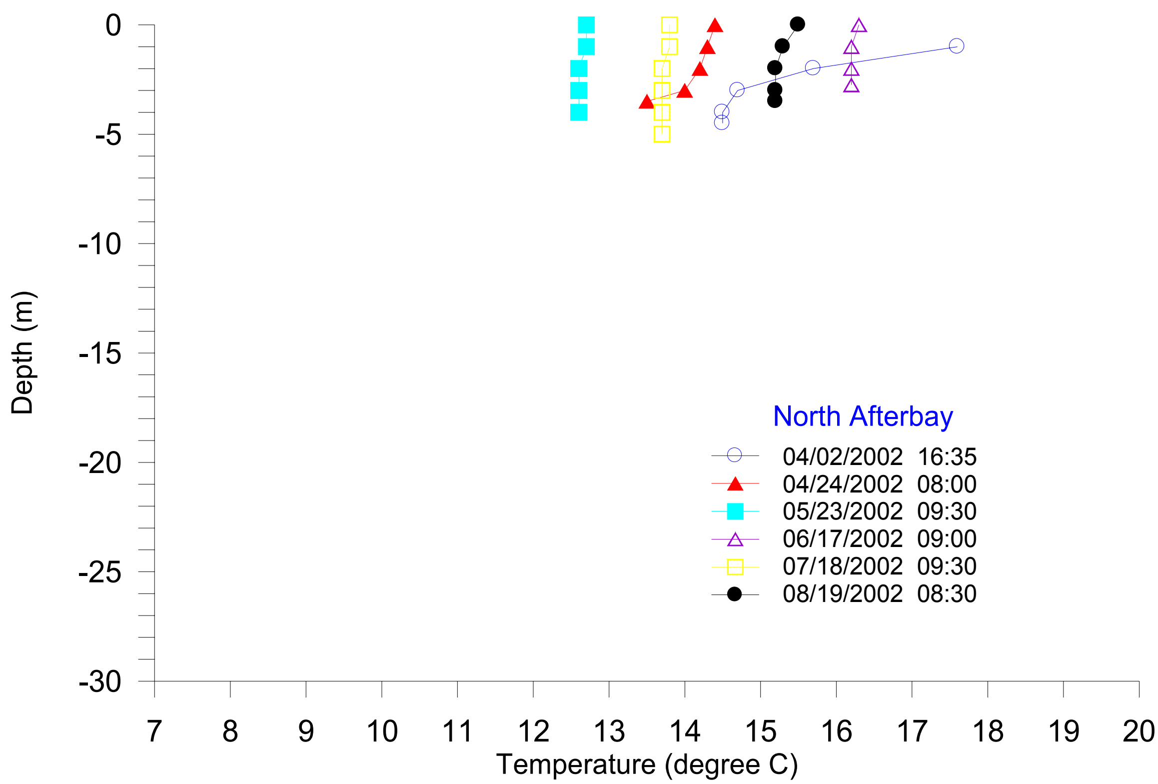


Figure 18 Temperature Profiles of Thermalito North Afterbay

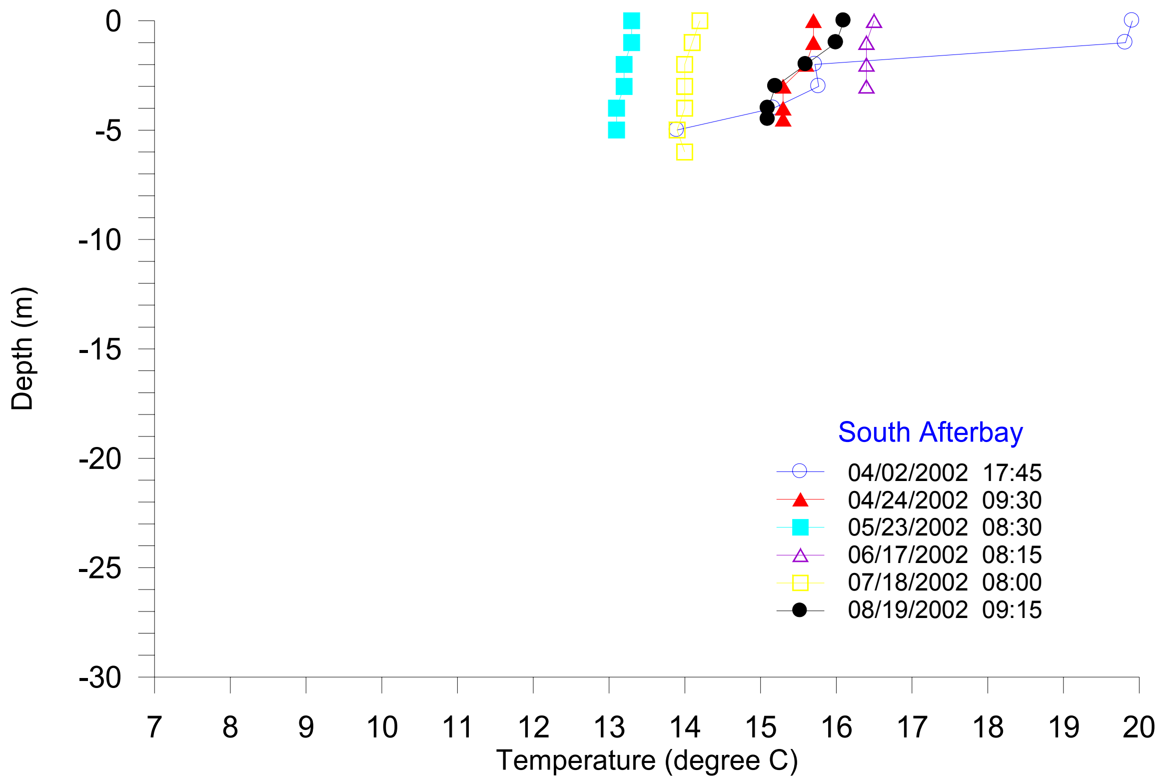


Figure 19 Temperature Profiles of Thermalito South Afterbay

The plots contradict our initial notion of stratification in the Thermalito Complex. The data shows that the Thermalito Diversion Pool is the most stratified and the Thermalito Forebay and Afterbay are weakly stratified.

The reason for the large stratification in the Thermalito Diversion Pool is that is is relatively deeper. Even though the Diversion Pool has a small surface area to adsorb solar energy, the stratification is maintained by continuous release of cold water from Hyatt Power Plant.

The Thermalito Forebay is fed by the Thermalito Power Canal. Because of its shallowness, the canal only takes warm water from the surface layers of the Diversion Pool. Even though the Forebay has a large surface area to adsorb solar energy, the stratification is weak because the water column starts with warm water with weak stratification, due to mixing in the Thermalito Power Canal. The shallow depth of the Forebay also promotes vertical mixing by winds, resulting in weak stratification.

The reason for weak stratification in the Thermalito Afterbay is similar to that for the Forebay. Shallow depth and wind mixing are primary causes for weak stratification.

In view of the foregoing discussion, we are setting up the model for the Thermalito Complex. We will model the complex as a series of stratified sections. The bathymetric data of each section is being compiled to set up the model similar to those discussed earlier for Lake Oroville.

TEMPERATURE MODEL OF THERMALITO DIVERSION POOL

The Thermalito Diversion Pool is a long and narrow impoundment, which is usually not a good candidate for 1D vertical temperature model. Due to budget and time constrains and also data availability, the 1D temperature model was used to simulate the temperature profiles of the diversion pool. It is hoped that the model can perform an adequate job of predicting the observed temperature profiles, with perhaps a quantifiable error. The magnitude of the quantifiable error can be considered during the interpretation of whether a proposed operational scenario can meet the temperature criteria for fish.

The 1D vertical temperature model is basically the same as the Lake Oroville model. Therefore, we needed the depth-volume and depth-area relationships of the Diversion Pool to set up the model. Figure 20 shows the depth volume relationship of the Diversion Pool. Figure 21 shows the depth area relationship. (Note that the 1D model requires only one curve for the entire Diversion Pool. More curves would be required by 2D or 3D models. Such data is not available at the present time).

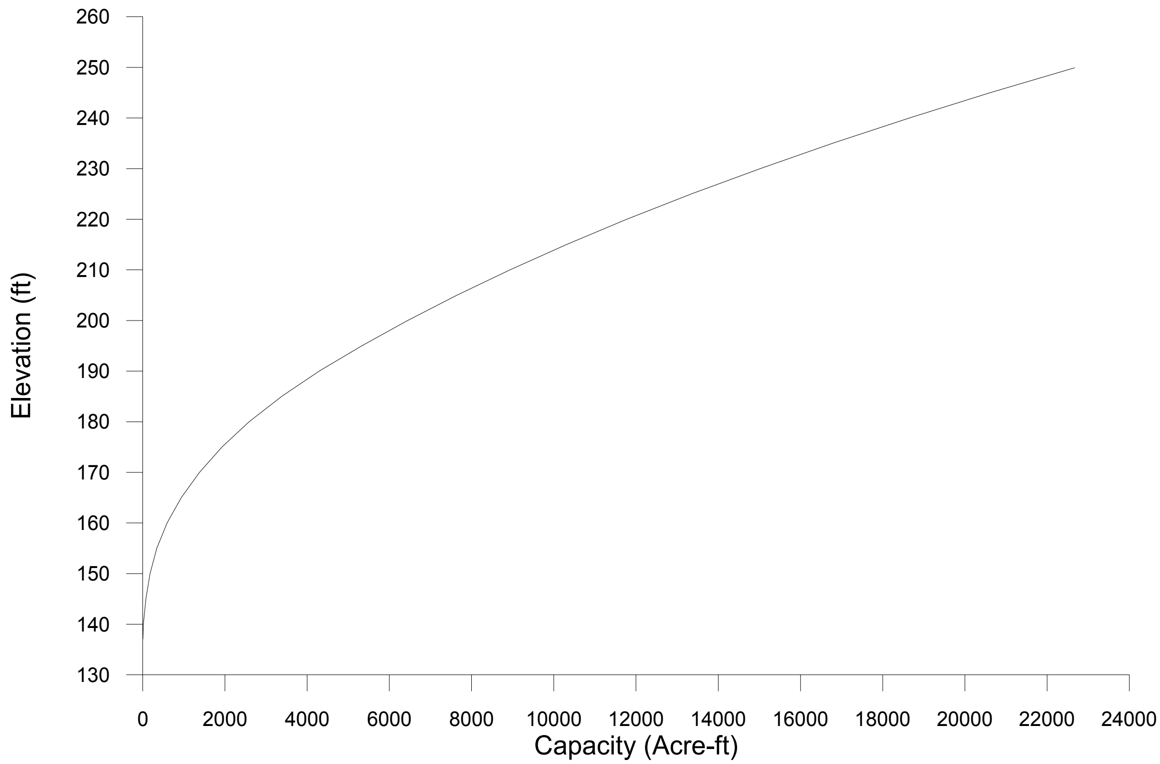


Figure 20 Depth Capacity Curve of Thermalito Diversion Pool.

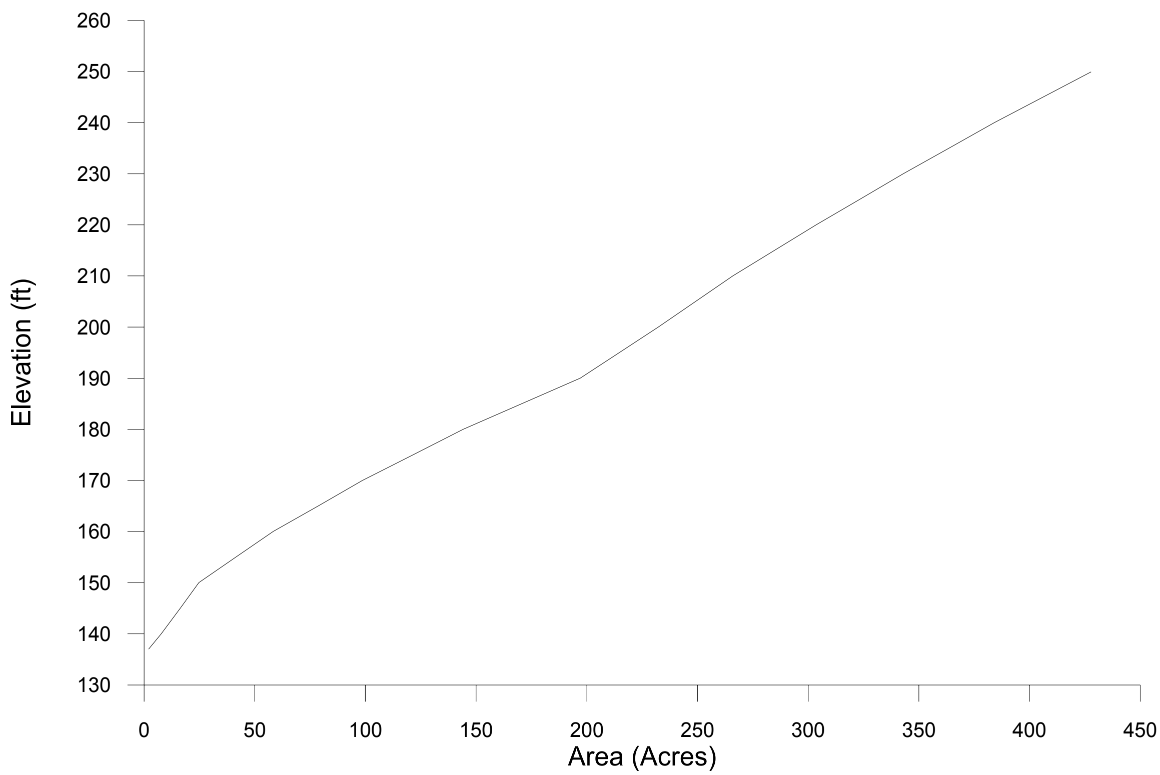


Figure 21 Depth Area Curve of Thermalito Diversion Pool

The depth volume and depth area relationships were used to set up the water layers for the 1D vertical temperature model. For Oroville Lake model, the layer thickness is one meter. For the Diversion Pool, which is relatively shallower, the layer thickness is 0.328 meter (1 foot).

The model also requires the specification of the inlets and outlets for the Thermalito Diversion Pool. Table 2 shows the inlet and outlet data compiled from DWR.

Table 2 Elevations of Inlets and Outlets of the Thermalito Diversion Pool

Elv (ft)	Description
200	Thermalito Power Canal
197	Diversion Dam Power Plant Generation
203	Fish Hatchery
200	Hyatt Powerplant Pumpback

Daily inflow and outflow data for the inlets and outlets shown above were obtained from DWR. The daily operational data was included in the spreadsheet for Thermalito Diversion Pool, together with Thermalito Power Canal and Thermalito Forebay, as shown in Table 3.

The computation time step is hourly. The daily flow data was divided into 24 hourly values for input to the model. The pump back was assumed to occur during the nights on week days and all hours on weekends.

Table 3 The Daily Operational Data for Thermalito Forebay, Power Canal, and Diversion Pool.

Thermalito Forebay
Including Diversion Pool and Power Canal

Daily Operation

Capacity: 25,120 ac-ft

(in acre-feet except as noted)

April 2002

Date	Storage 1/	Storage Change	Inflow: Lake Oroville Releases 2/	Inflow: Kelly Ridge Generation	Inflow: Thermalito Pumping-Generating Plant Pumpback	Outflow: Thermalito Pumping-Generating Plant Generation 3/	Outflow: Butte County	Outflow: Thermalito Irrigation District	Outflow: Releases To River 4/	Outflow: Hyatt Powerplant Pumpback	Losses (-) And Gains (+)
Mar 31	23,908										
1	24,013	105	4,423	505	1,314	3,457	0	6	1,255	1,039	-380
2	23,964	-49	3,052	510	0	2,674	0	6	1,257	0	326
3	24,057	93	3,652	505	0	2,885	0	6	1,275	0	102
4	23,968	-89	3,517	541	1,593	3,642	0	6	1,267	902	77
5	23,793	-175	4,050	478	2,048	4,348	0	6	1,261	1,203	67
6	24,261	468	437	505	2,145	173	0	6	1,257	1,223	40
7	22,482	-1,779	76	488	6,232	0	0	6	1,253	7,486	170
8	24,099	1,617	1,789	506	1,618	178	0	6	1,249	902	39
9	23,709	-390	2,665	510	0	2,380	0	6	1,253	0	74
10	24,053	344	2,330	506	0	1,219	0	6	1,249	0	-18
11	23,945	-108	3,276	466	0	2,659	0	6	1,251	0	66
12	23,981	36	4,662	436	1,026	4,279	0	6	1,241	587	25
13	24,274	293	3,394	432	0	2,329	0	6	1,241	0	43
14	23,881	-393	2,457	500	780	2,057	0	6	1,239	826	-2
15	23,878	-3	3,515	502	1,319	2,821	0	6	1,237	1,337	62
16	23,759	-119	4,119	549	792	3,539	1	6	1,259	797	23

17	23,895	136	5,148	454	1,002	4,352	1	6	1,255	977	123
18	23,685	-210	4,604	512	0	4,151	1	6	1,251	0	83
19	24,040	355	6,781	504	1,549	6,424	1	6	1,255	781	-12
20	23,634	-406	3,252	510	0	3,042	1	6	1,251	0	132
21	23,526	-108	4,114	510	1,321	3,847	1	6	1,247	1,051	99
22	24,104	578	7,529	508	0	6,389	1	6	1,247	0	184
23	23,578	-526	6,557	508	0	6,343	1	6	1,253	0	12
24	23,762	184	7,283	296	2,079	6,983	1	6	1,249	1,550	315
25	23,646	-116	7,878	508	1,885	7,489	1	6	1,249	1,696	54
26	23,546	-100	8,739	510	2,568	9,564	1	6	1,253	1,350	257
27	24,060	514	5,590	514	0	4,422	1	6	1,253	0	92
28	24,053	-7	5,563	508	0	4,903	1	6	1,253	0	85
29	23,732	-321	9,159	500	0	8,770	1	6	1,263	0	60
30	23,874	142	8,782	508	0	8,047	1	6	1,263	0	169
Total		-34	138,393	14,789	29,271	123,366	15	180	37,586	23,707	2,367

1/ Sum of Thermalito Forebay and Diversion Pool.

2/ Sum of releases from Lake Oroville through Hyatt plant, and spill.

3/ Includes Bypass flows at Thermalito.

4/ The sum of the flows from fish barrier dam and the fish hatchery.

The model also requires meteorological data. The data from Durham Weather Station was assumed to be applicable to the Diversion Pool as well.

Based on the input data described above, the model performed water budget calculations to predict the daily lake surface elevations. Figure 22 shows the comparison of simulated and observed lake surface elevations. The maximum error of the model prediction is less than 0.3 foot.

Figures 23 to 26 compare the simulated and observed temperature profiles for dates 4/3/02, 4/22/02, 5/22/02, and 6/18/02 respectively. The maximum error of prediction is approximately two degrees Celsius.

The progression of thermal stratifications in the Diversion Pool is different from that in Oroville Lake. In Oroville Lake, the stratification becomes stronger as the season progresses from spring to summer. The size of the lake is so large that the water has a long residence time for the sun to heat it from the top. In the Diversion Pool, the stratification was strong on April 3, 2002, but not as strong as the season progressed. This is because the size of the Diversion Pool is small. The stratification in the Diversion Pool is controlled by the releases of warm or cold water from Hyatt Powerplant as well as by solar radiation.

Figure 27 compares simulated temperatures of outflow from the Thermalito Diversion Pool to the Thermalito Forebay through the Thermalito Power Canal. The model appears to be tracking the trend of outflow temperatures very well for the entire simulation periods. However, the model has under predicted the temperatures by one to two degrees Celsius.

There are several possible reasons for the discrepancy of model predictions. First, the model simulated the outflow temperatures at the eastern end of the power canal, where as the observed temperatures were measured at the western end of the power canal. The water might gain heat and became warmer as it moved through the power canal. Second, the water at the monitoring station might include the surface water of the Thermalito Forebay, which might be warmer. Third, the thermometer was placed at one point, which might not measure the average temperatures simulated by the model.

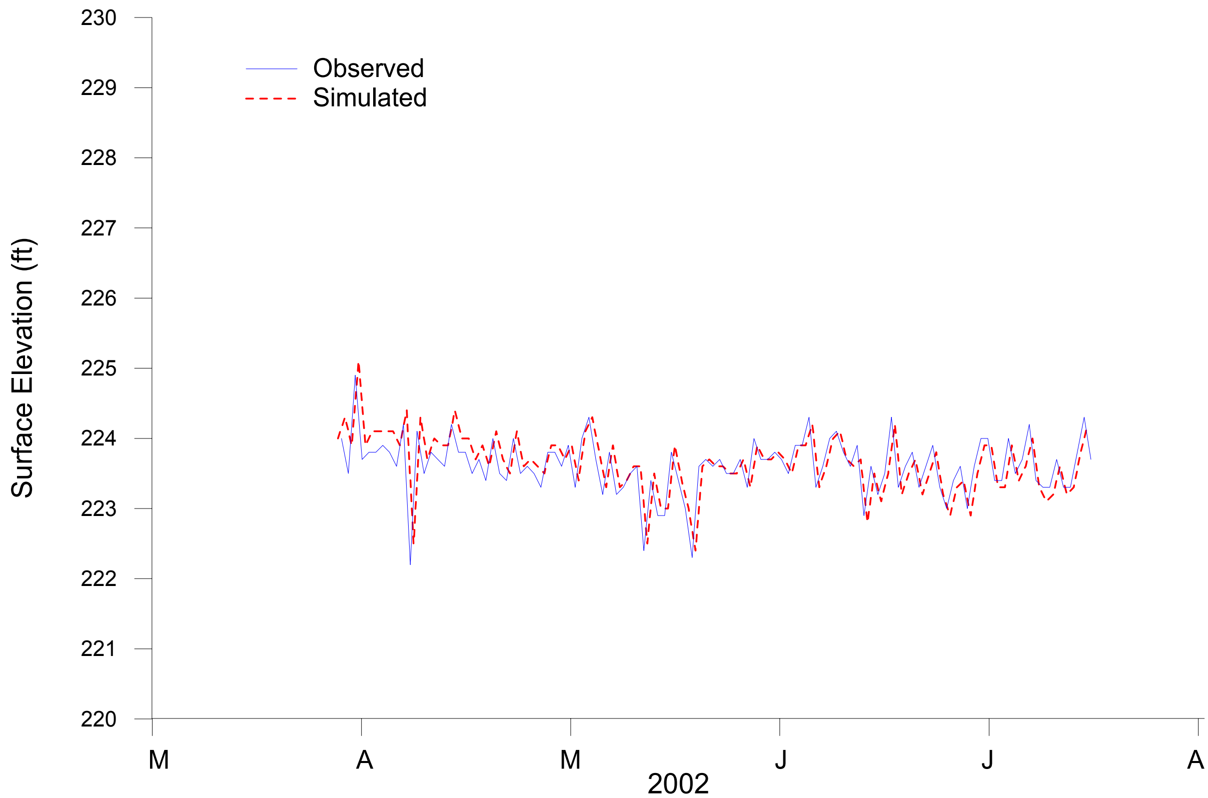


Figure 22 Comparison of the Simulated and Observed Lake Surface Elevations

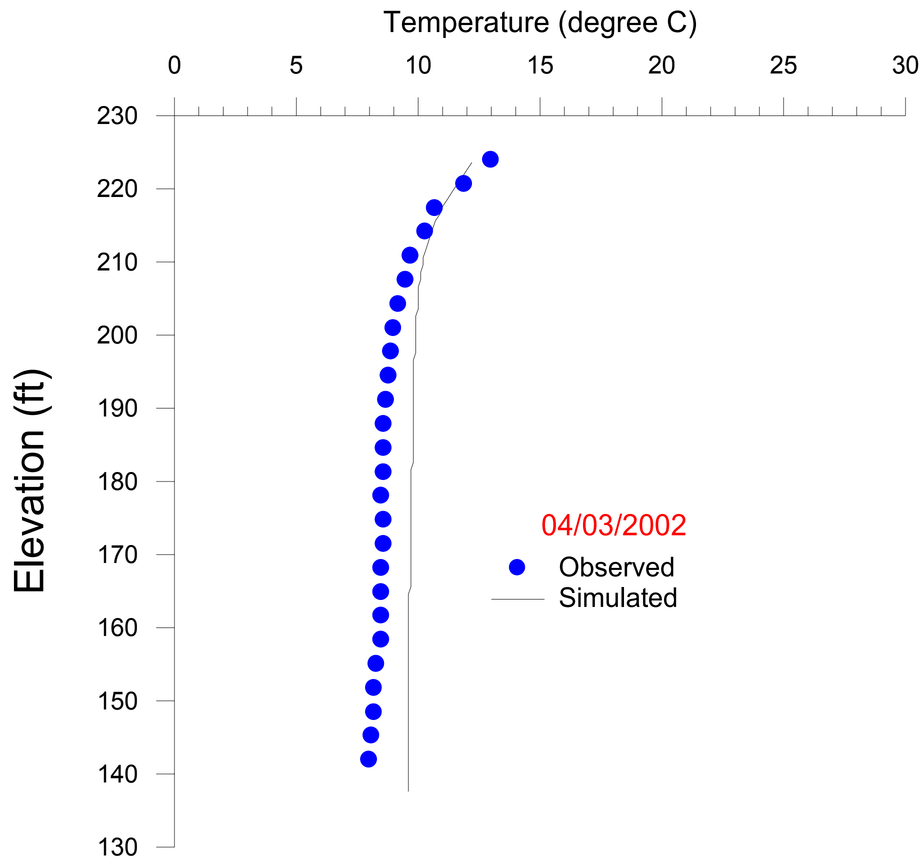


Figure 23 Comparison of Simulated and Observed Temperature Profiles of the Thermalito Diversion Pool for April 3, 2002.

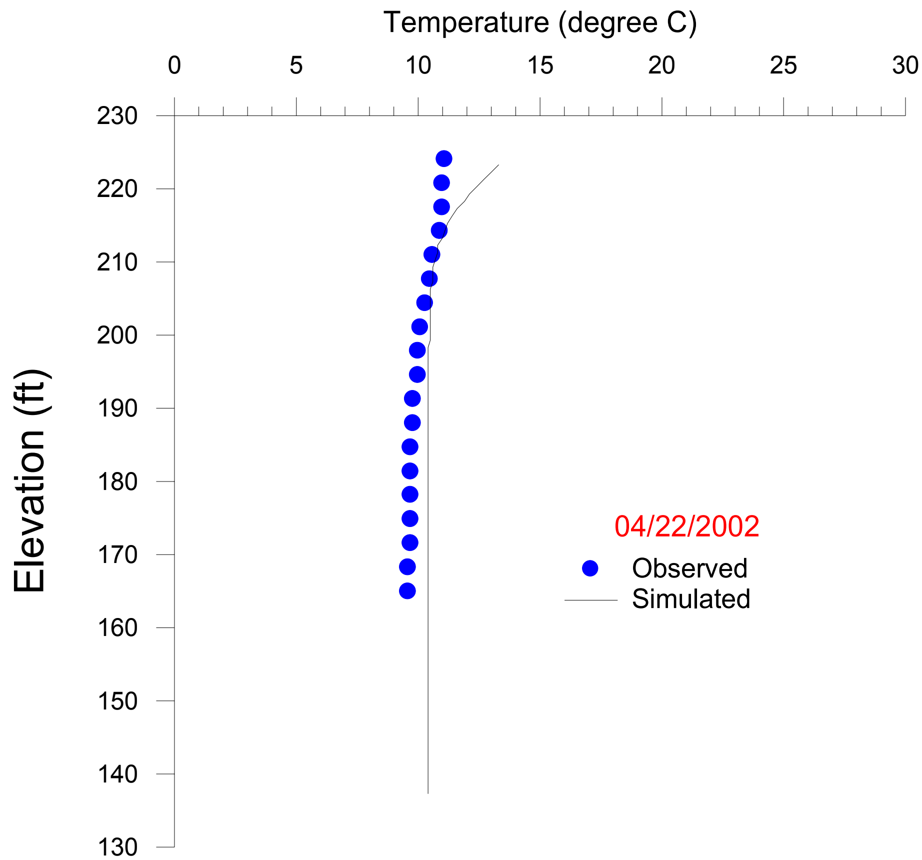


Figure 24 Comparison of Simulated and Observed Temperature Profiles of the Thermalito Diversion Pool for April 22, 2002.

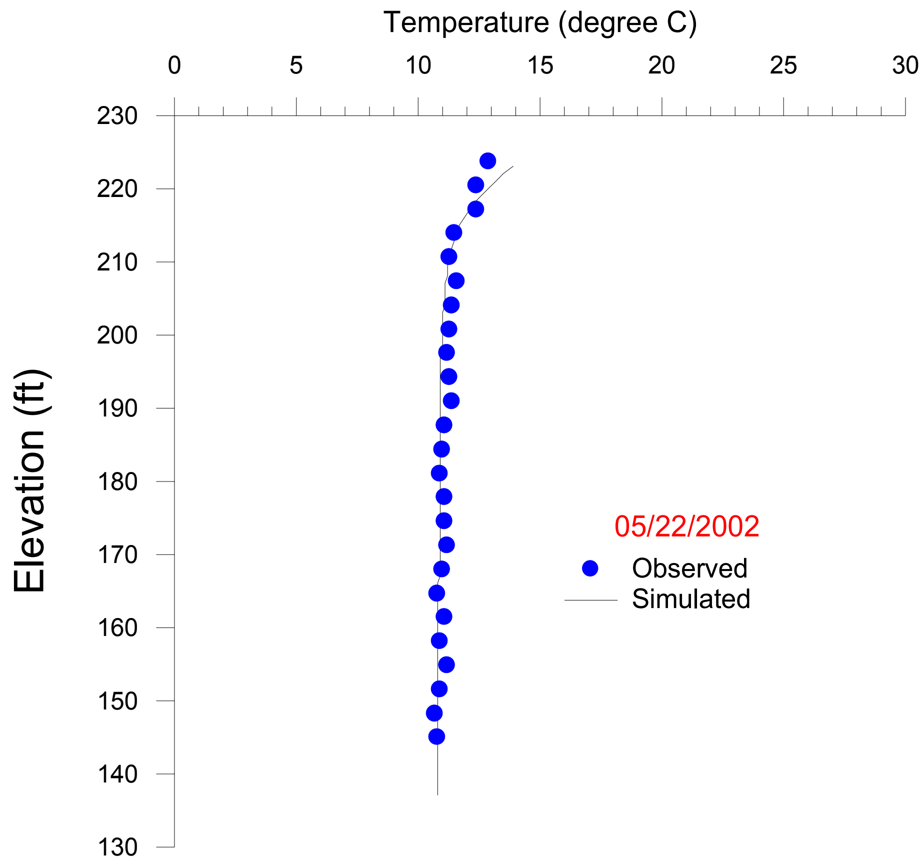


Figure 25 Comparison of Simulated and Observed Temperature Profiles of the Thermalito Diversion Pool for May 22, 2002.

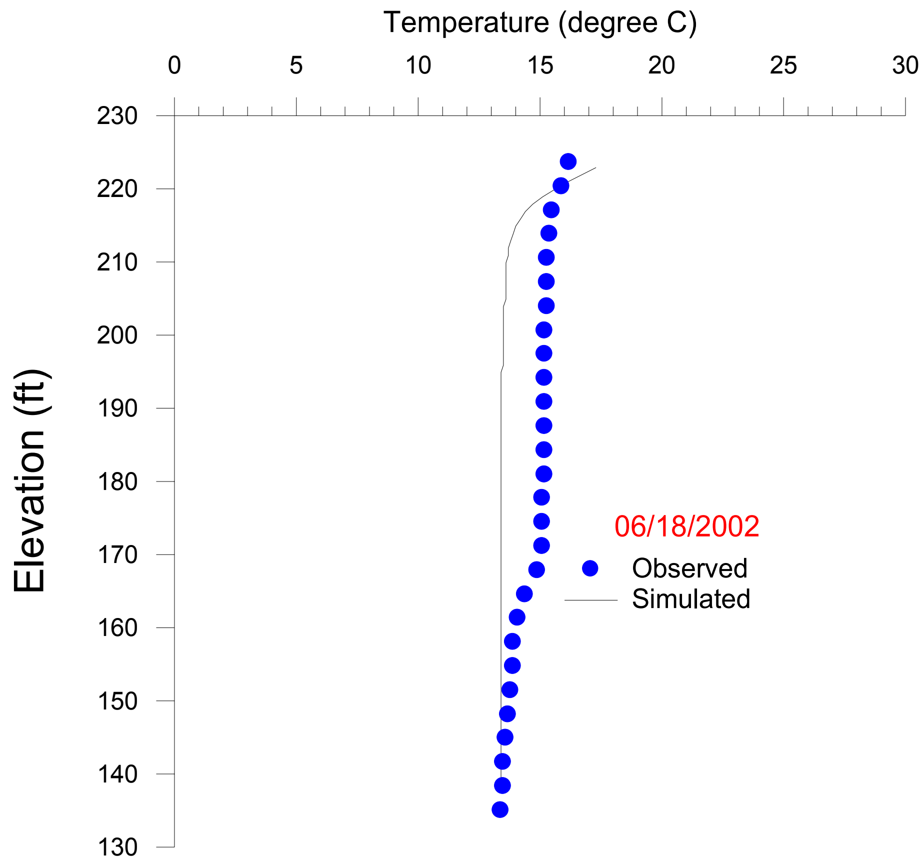


Figure 26 Comparison of Simulated and Observed Temperature Profiles of the Thermalito Diversion Pool for June 18, 2002.

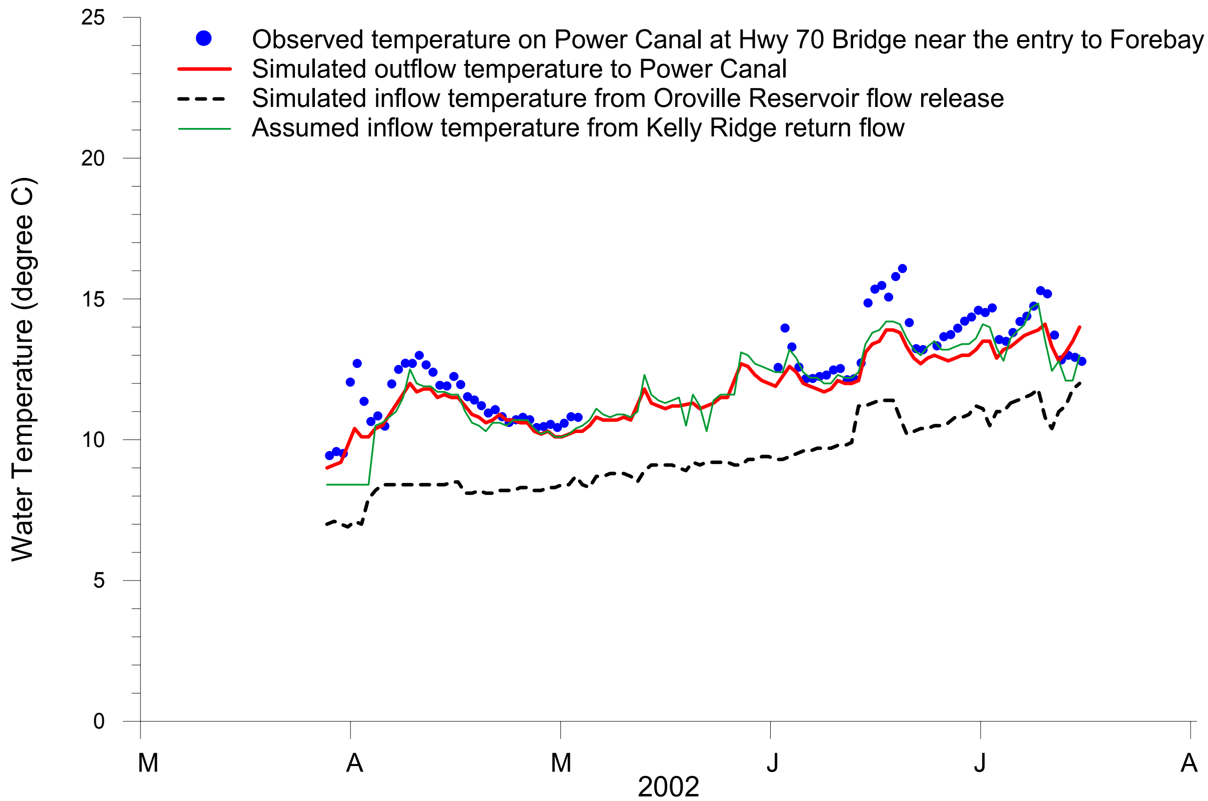


Figure 27 Simulated and Observed Outflow Temperatures to T. Power Canal

Figure 27 also shows temperatures of inflows to the Thermalito Diversion Pool. The plot indicates that the water temperatures gained about 3 to 4 degrees Celsius in the Diversion Pool.

Based on the results presented above, the 1D vertical temperature model appears to have done a reasonable job of predicting the temperature profiles of the Thermalito Diversion Pool and the outflow temperatures of the Thermalito Power Canal. Some fine tuning can still be made to improve the model results. The final model can be used to predict the temperatures for environmental impact analyses.

TEMPERATURE MODEL OF THERMALITO FOREBAY

The 1D vertical temperature model was also used to simulate the temperature profiles of Thermalito Forebay. Figure 28 is the depth capacity curve and Figure 29 is the depth area curve of the Thermalito Forebay, which includes the water in the Power Canal. The water layers for heat budget calculations have a thickness of 0.328 m (1 foot).

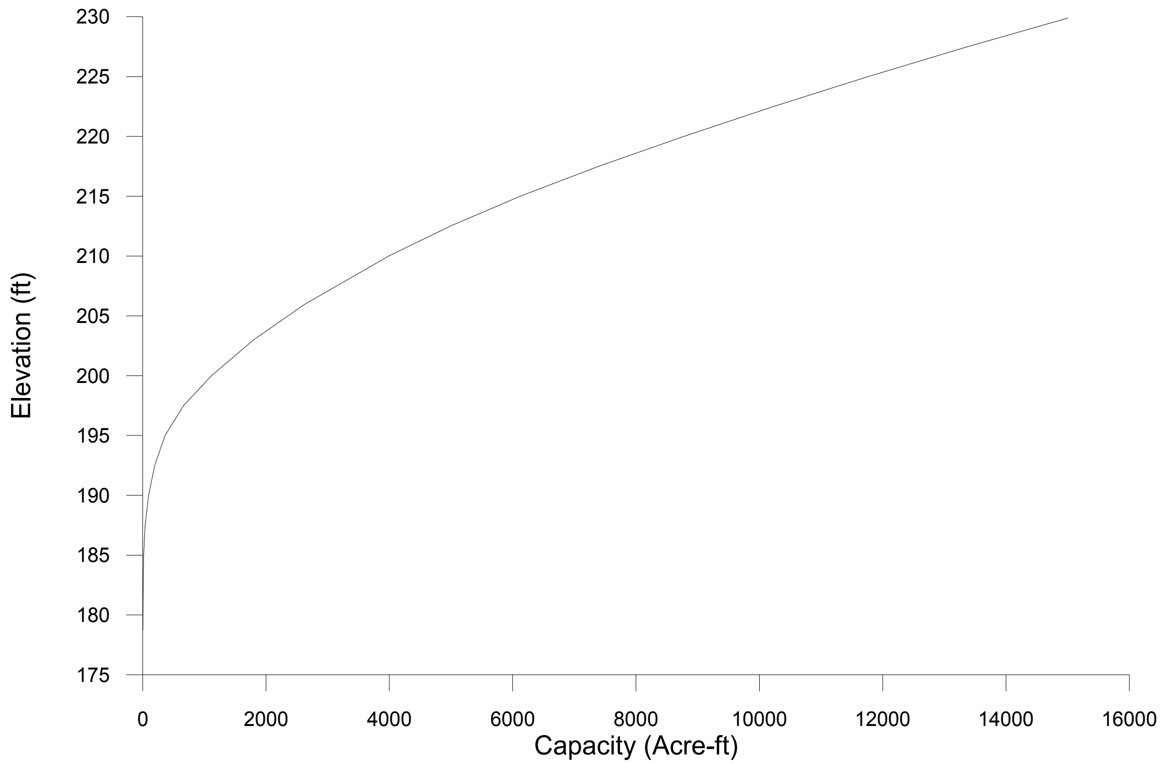


Figure 28 Depth Capacity Curve for Thermalito Forebay

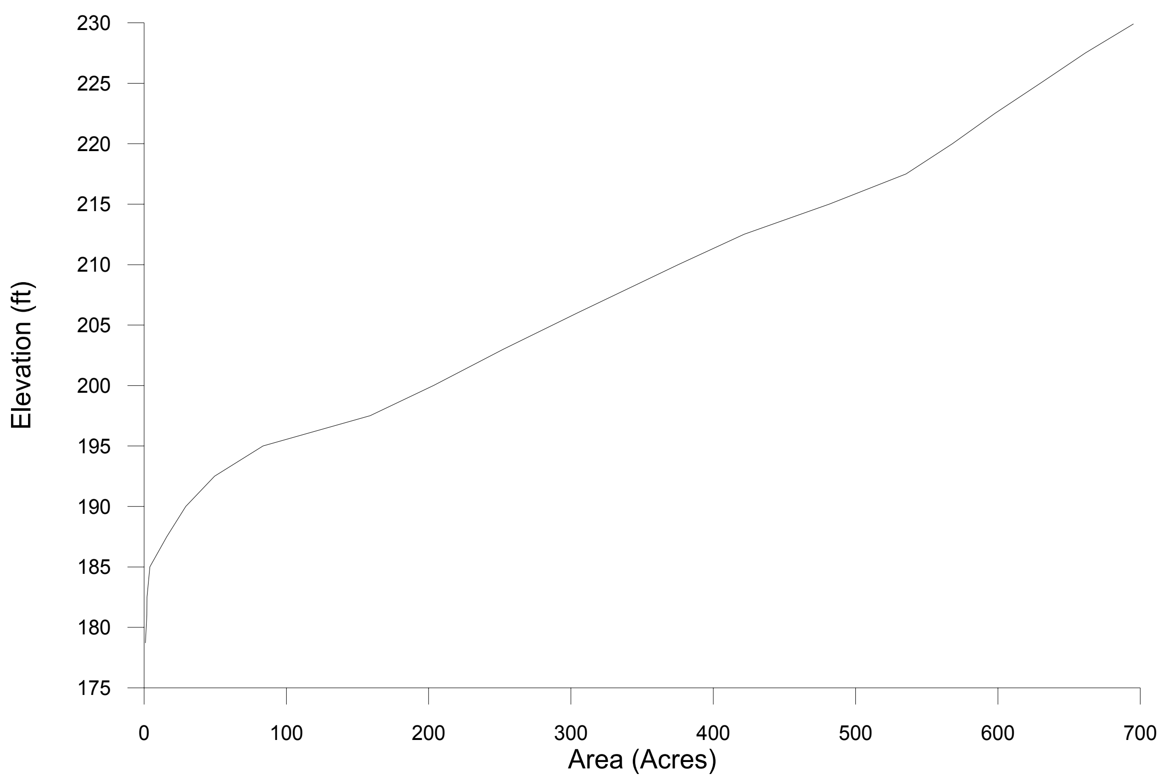


Figure 29 Depth Area Curve for Thermalito Forebay

The information about the inlets and outlets of Thermalito Forebay is presented in Table 4.

Table 4 Elevations of the Inlets and Outlets of Thermalito Forebay

Elv (ft)	Description
200	Thermalito Pumping-Generating Plant Pumpback
199	Thermalito irrigation District
198	Butte County
197	Thermalito Pumping-Generating Plant Generation
188	Thermalito Pumping-Generating Plant Bypass

The daily flow data for the inlets and outlets is included in Table 3, which was presented in the section above. In the table, there is a term for losses and gains. This is actually an error term for flow balance, based on daily gage data of inflow and outflow to the Diversion Pool, Power Canal, and Thermalito Forebay. The term may represent flow measurement error, local drainage, and evaporation. Figure 30 shows the magnitude of the term.

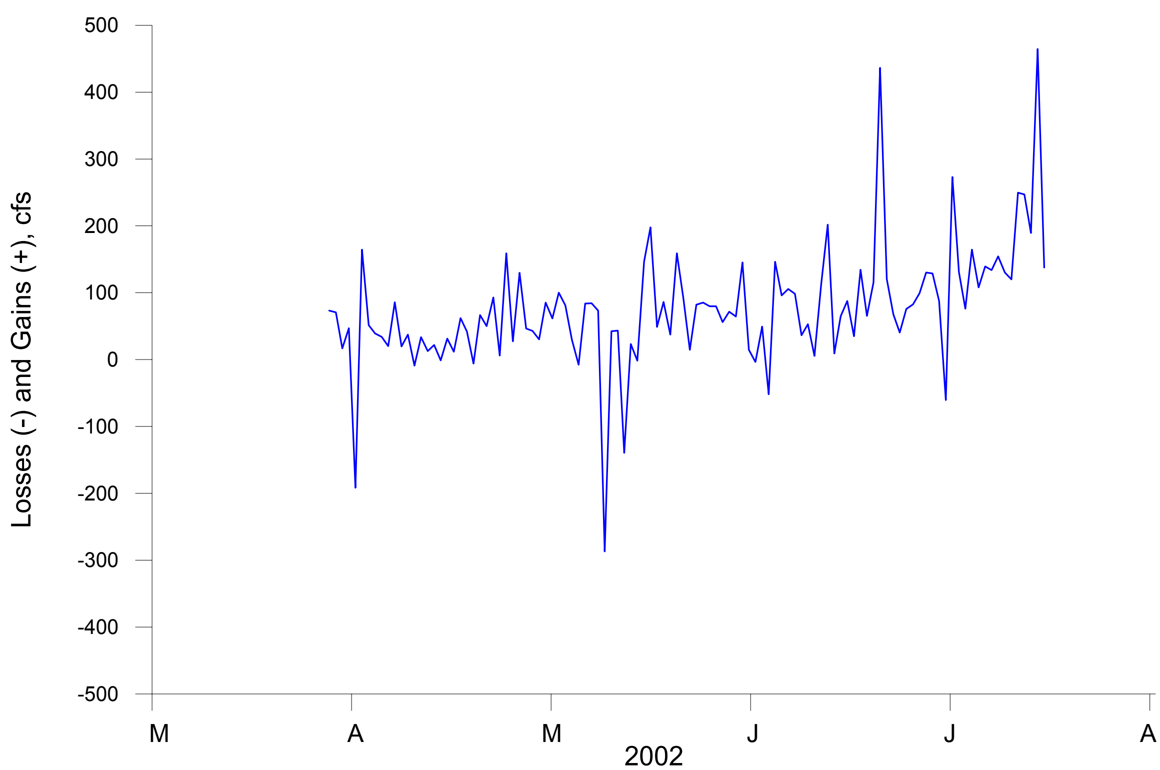


Figure 30 Losses and Gains of Water for Thermalito Diversion Pool, Power Canal and Thermalito Forebay

For this simulation, the loss and gain term was accounted for by the inflow to the Thermalito Forebay. The time step of computation is hourly.

Figure 31 shows the comparison of simulated and observed lake surface elevations of Thermalito Forebay. The match is reasonably good, even though there is a double accounting of evaporation loss by the model. This is because the evaporation loss was already included in the loss and gain term. The evaporation is already accounted for by the adjustment of inflow to the Forebay. Yet, the temperature model still simulates the evaporation loss and subtracts it from the lake surface elevation. Perhaps, that is why the simulated surface elevations are generally lower than the observed surface elevations. However, we believe that the error introduced by the double accounting of evaporation loss is probably small due to the small surface area of Thermalito Forebay.

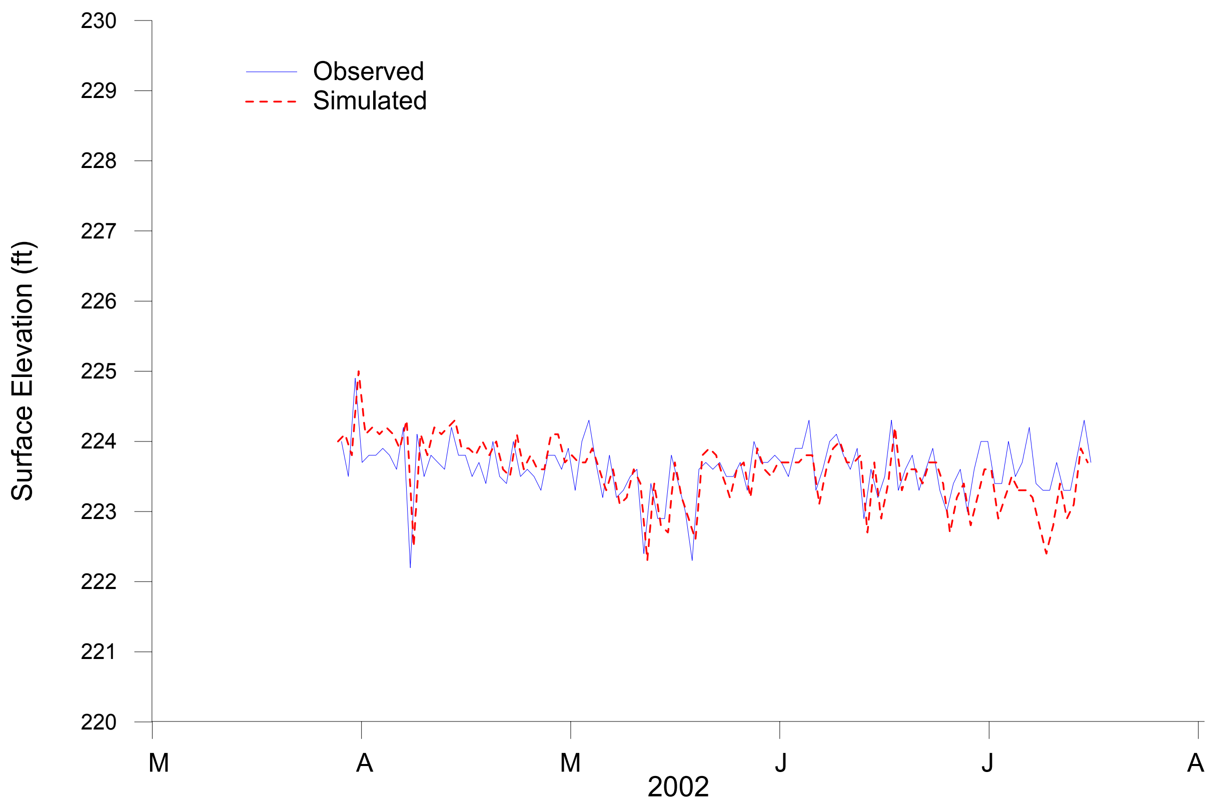


Figure 31 Comparison of Simulated and Observed Surface Elevations of Thermalito Forebay.

Figure 32 presents the locations of temperature monitoring stations for the Power Canal and Thermalito Forebay. The data for the Power Canal Station has been used to compare the simulated outflow temperature of the Diversion Pool, which becomes the inflow temperature to Thermalito Forebay.

There are two temperature profile stations in the Forebay. But the 1D vertical temperature model simulates only one temperature profile for Thermalito Forebay. Figures 33 to 36 compare the simulated and observed temperature profiles for 4/2/02, 4/29/02, 5/22/02, and 6/17/02 respectively. The model appears to have simulated the temperature profiles reasonably well. The errors are generally within one degree Celsius.

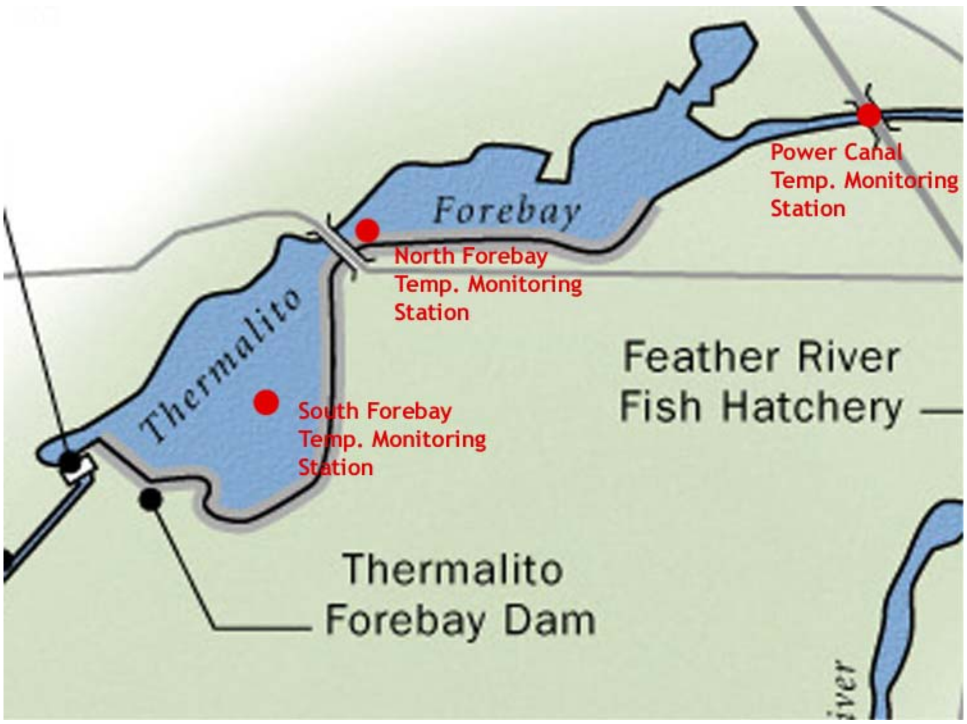


Figure 32 Temperature Monitoring Stations of Thermalito Power Canal and Thermalito Forebay.

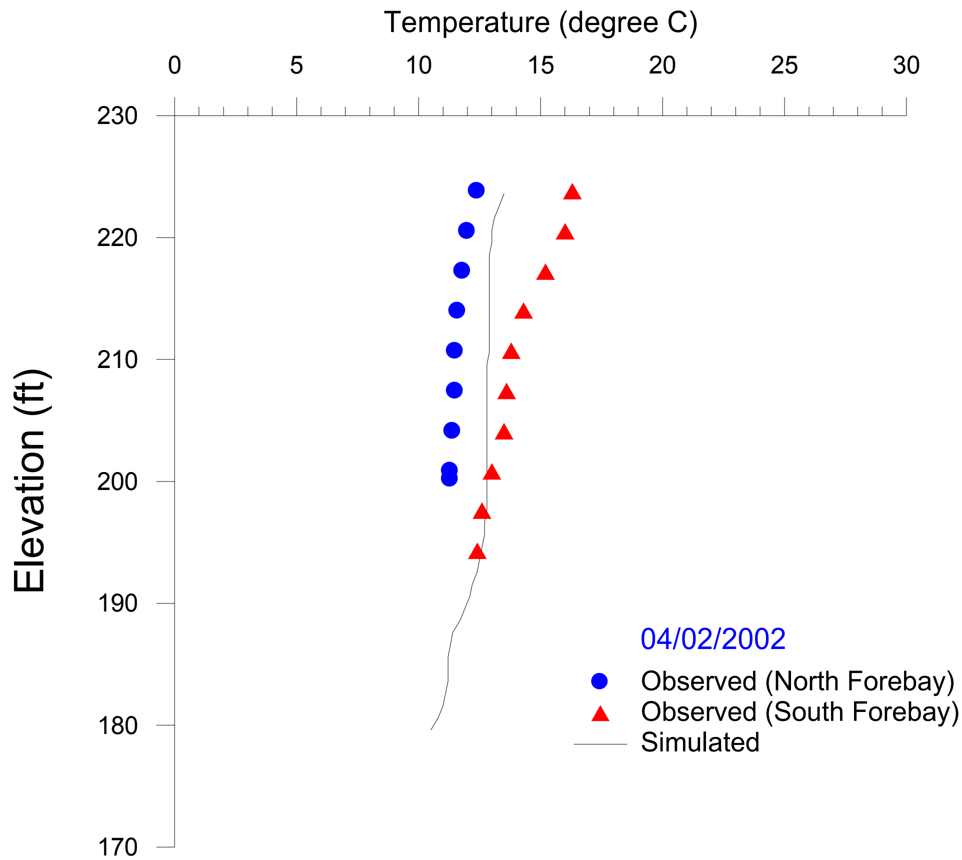


Figure 33 Simulated and Observed Temperature Profile of Thermalito Forebay for April 2, 2002

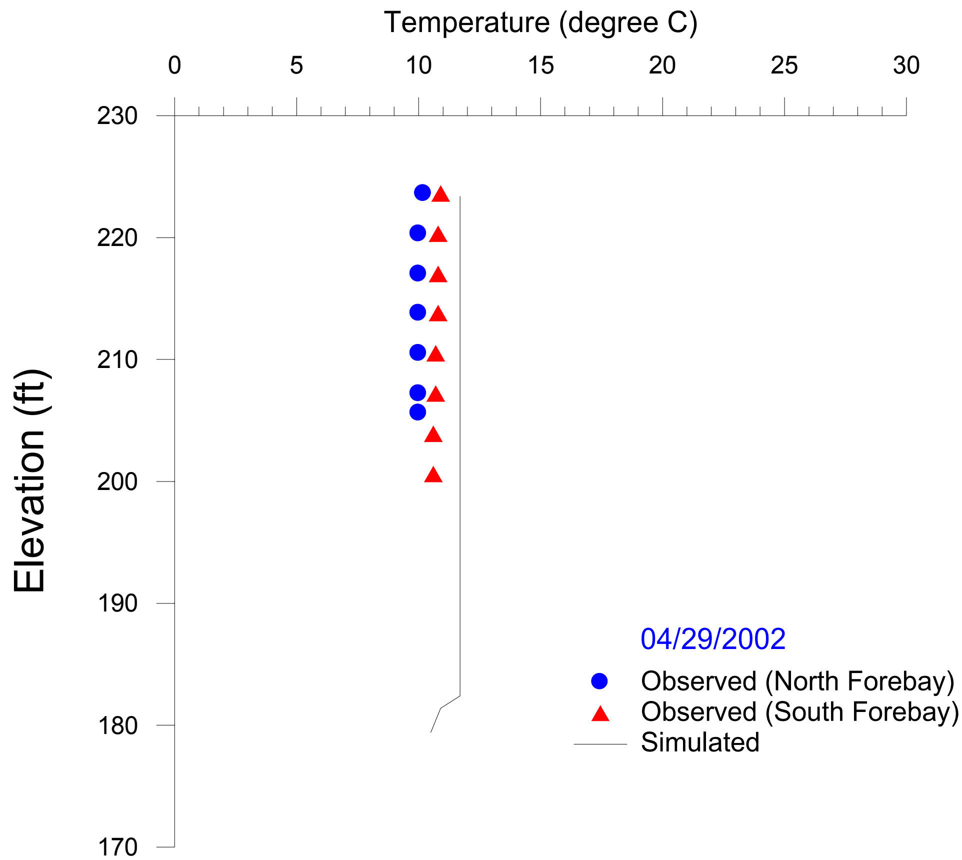


Figure 34 Simulated and Observed Temperature Profile of Thermalito Forebay for April 29, 2002

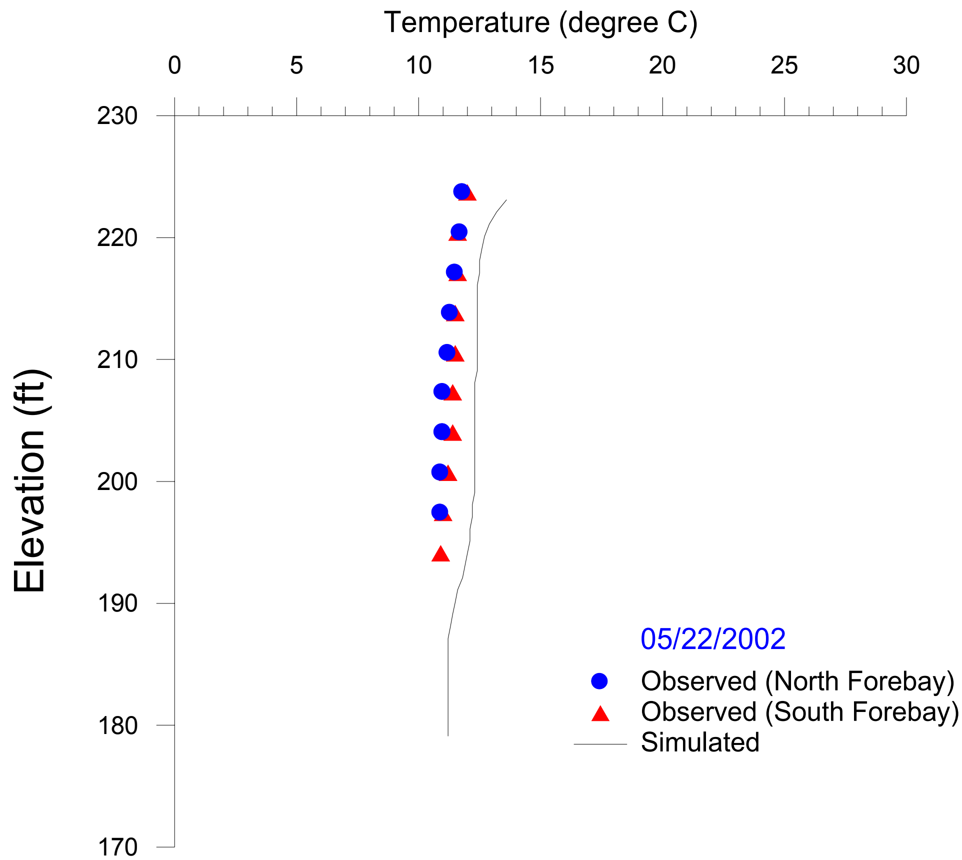


Figure 35 Simulated and Observed Temperature Profile of Thermalito Forebay for May 22, 2002

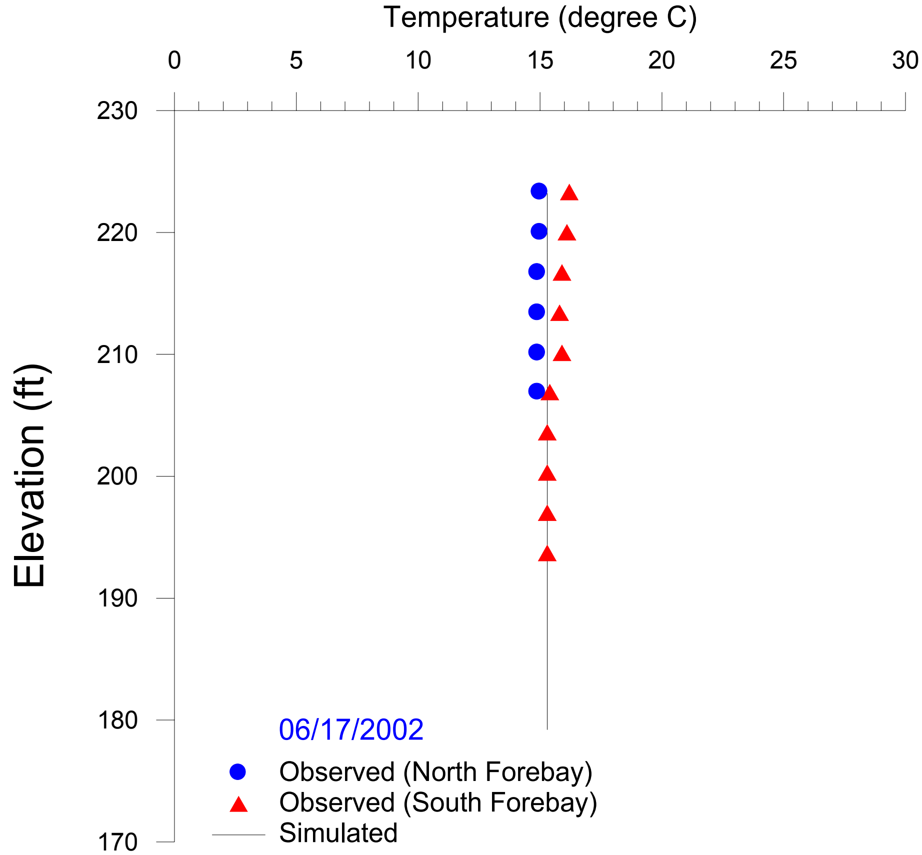


Figure 36 Simulated and Observed Temperature Profile of Thermalito Forebay for June 17, 2002

TEMPERATURE MODEL OF THERMALITO AFTERBAY

The 1D vertical temperature model was applied to simulate the temperature profiles of Thermalito Afterbay. Figure 37 is the depth capacity curve and Figure 38 is the depth area curve of Thermalito Afterbay. Thermalito Afterbay water was segmented into 0.328 m (1 foot) layers for heat budget calculations.

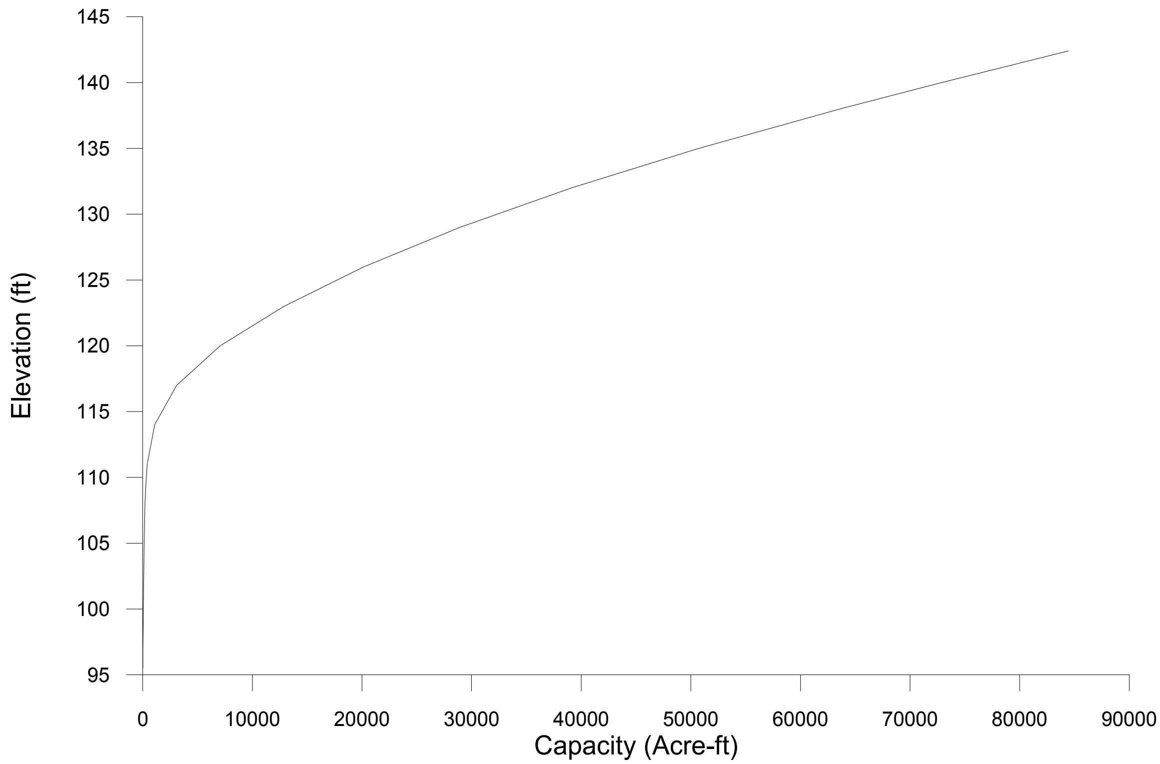


Figure 37 Depth Capacity Curve of Thermalito Afterbay

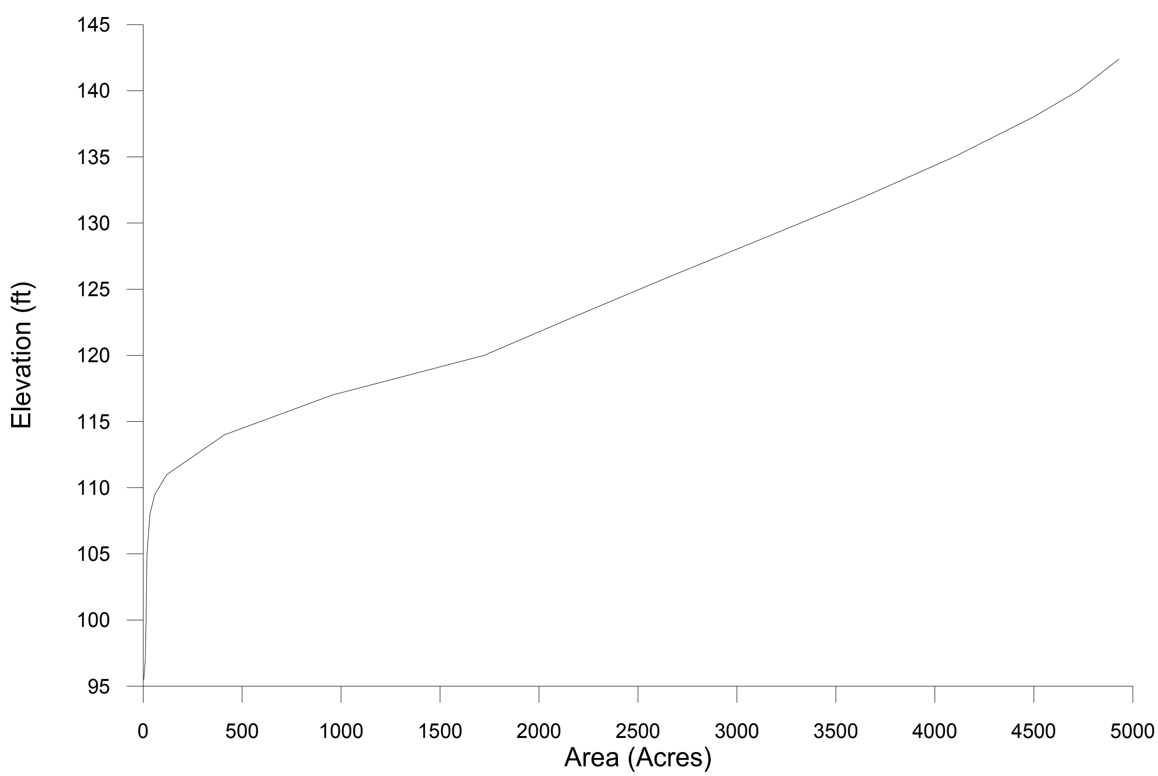


Figure 38 Depth Area Curve of Thermalito After Bay.

Table 5 provides information about the inlets and outlets of the Thermalito Afterbay. Table 6 provides the daily operational data of Thermalito Afterbay for April 2002. The data for April through July was obtained from DWR for input to the model.

Table 5 Inlets and Outlets of the Thermalito Afterbay

Elv (ft)	Description
102	Thermalito Pumping-Generating Plant Pumpback
109	Western Canal
108	Richvale Canal
112	Western Canal Lateral
105	Sutter Butte Canal
113	Feather River

The meteorological data of the Durham weather station was also used as input data to drive the temperature model. The time step of computation is hourly.

Table 6 Daily Operational Data of Thermalito Afterbay for April 2002

Thermalito Afterbay

Daily Operation

(in acre-feet except as noted)

Capacity: 57,040 ac-ft

April 2002

Date	Water Surface Elevation (in feet)	Storage	Storage Change	Inflow	Outflow						Losses (-) and Gains (+)	Total Releases to River 2/
				Thermalito Pumping-Generating Plant Generation 1/	Sutter Butte Canal	Western Canal Lateral	Richvale Canal	Western Canal	Afterbay River Outlet	Thermalito Pumping-Generating Plant Pumpback		
Mar 31	129.67	31,064										
1	129.93	31,919	855	3,457	0	0	0	0	1,155	1,314	-133	2,410
2	130.39	33,460	1,541	2,674	0	0	0	0	1,162	0	29	2,419
3	130.88	35,139	1,679	2,885	0	0	0	0	1,148	0	-58	2,423
4	131.15	36,080	941	3,642	0	0	0	0	1,162	1,593	54	2,429
5	131.39	36,927	847	4,348	0	0	0	0	1,159	2,048	-294	2,420
6	130.47	33,731	-3,196	173	0	0	0	0	1,142	2,145	-82	2,399
7	128.30	26,737	-6,994	0	0	0	0	0	1,152	6,232	390	2,405
8	127.41	24,092	-2,645	178	0	0	0	61	1,155	1,618	11	2,404
9	127.76	25,116	1,024	2,380	0	0	0	95	1,159	0	-102	2,412
10	127.58	24,587	-529	1,219	308	0	0	151	1,160	0	-129	2,409
11	127.89	25,502	915	2,659	397	0	0	192	1,152	0	-3	2,403
12	128.35	26,889	1,387	4,279	468	0	0	194	1,155	1,026	-49	2,396
13	128.49	27,319	430	2,329	496	0	45	188	1,141	0	-29	2,382
14	128.39	27,012	-307	2,057	494	0	112	190	1,159	780	371	2,398
15	128.06	26,011	-1,001	2,821	581	0	180	282	1,159	1,319	-301	2,396
16	128.16	26,312	301	3,539	722	0	264	363	1,162	792	65	2,421

17	128.31	26,767	455	4,352	881	0	301	393	1,162	1,002	-158	2,417
18	128.65	27,813	1,046	4,151	1,083	0	305	393	1,166	0	-158	2,417
19	129.16	29,417	1,604	6,424	1,246	0	305	450	1,152	1,549	-118	2,407
20	128.96	28,783	-634	3,042	1,440	0	389	561	1,152	0	-134	2,403
21	128.49	27,319	-1,464	3,847	1,533	0	462	712	1,160	1,321	-123	2,407
22	129.06	29,099	1,780	6,389	1,843	0	549	906	1,154	0	-157	2,401
23	129.41	30,219	1,120	6,343	2,182	0	573	1,055	1,150	0	-263	2,403
24	129.15	29,385	-834	6,983	2,579	8	595	1,085	1,159	2,079	-312	2,408
25	129.06	29,099	-286	7,489	2,916	13	674	1,218	1,159	1,885	90	2,408
26	129.26	29,737	638	9,564	3,134	26	732	1,394	1,166	2,568	94	2,419
27	128.40	27,042	-2,695	4,422	3,392	28	764	1,482	1,162	0	-289	2,415
28	127.63	24,734	-2,308	4,903	3,431	28	734	1,531	1,159	0	-328	2,412
29	128.34	26,859	2,125	8,770	3,392	60	795	1,581	1,154	0	337	2,417
30	128.55	27,504	645	8,047	3,352	69	821	1,583	1,154	0	-423	2,417
Total			-3,560	123,366	35,870	232	8,600	16,060	34,691	29,271	-2,202	72,277

1/ Includes Bypass flows at Thermalito.

2/ The sum of the flows from the fish barrier dam, fish hatchery, and afterbay river outlet.

The daily operational data includes the losses and gains. They are the errors of water budget based on gaged inflows and outflows. Their magnitudes are shown in Figure 39.

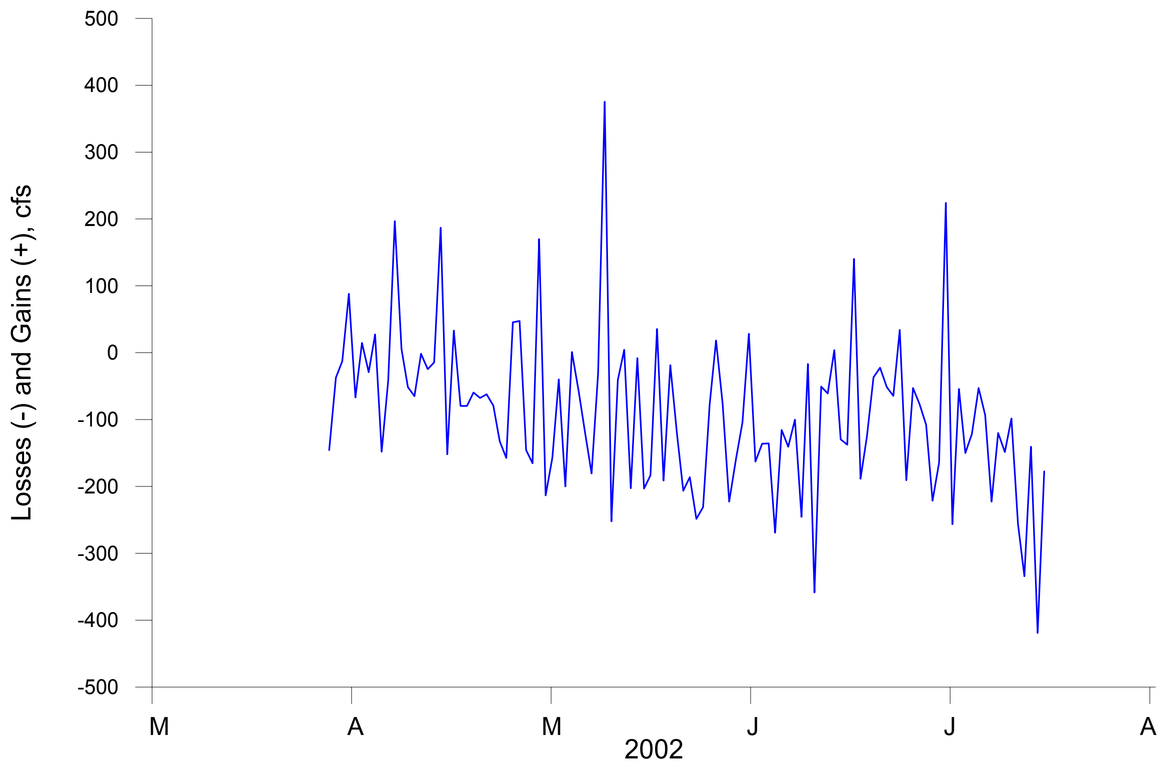


Figure 39 Losses and Gains of Water Balance for Thermalito Afterbay

The losses and gains include measurement errors, evaporation loss, and unaccounted inflows. In the initial simulation runs, we adjusted the data for inflows to Thermalito Afterbay to account for the losses and gains, in a manner similar to the model set up for Thermalito Forebay. Due to double accounting of evaporation losses, we discovered that the model predicted the lake surface elevations too low. We therefore ran the model first to simulate the evaporation loss from Thermalito Afterbay's surface. We then subtracted the evaporation loss from the loss-gain term and adjusted the inflows accordingly. This procedure requires one extra step in the model simulation. However, it was necessary because the surface area of Thermalito Afterbay, and its evaporation loss are quite large.

Figure 40 shows a comparison of simulated and observed surface elevations of Thermalito Afterbay. This good match has been achieved by eliminating the double accounting of evaporation loss.

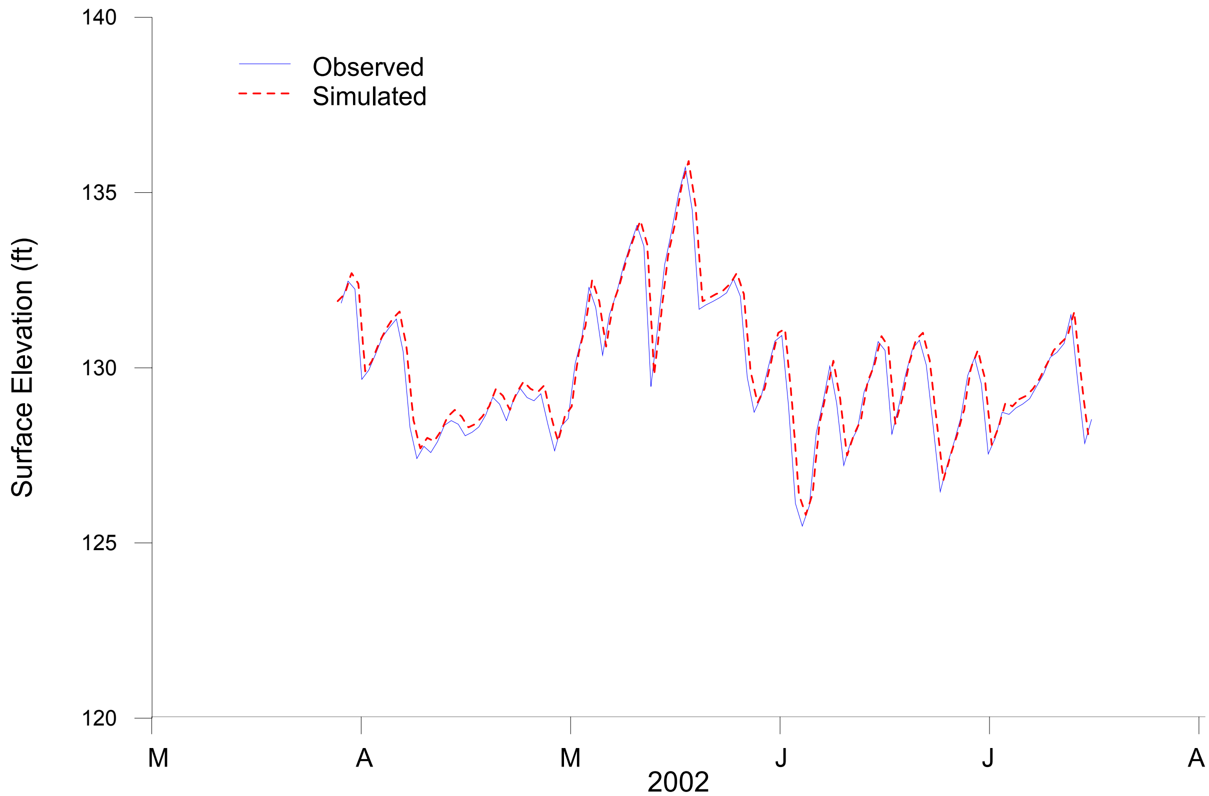


Figure 40 Simulated and Observed Surface Elevations of Thermalito Afterbay.

Figure 41 shows the locations where DWR took the temperature profiles. Both the north and south monitoring stations are located at the upstream section far removed from the outlet station. Since the 1D vertical temperature model predicts only one temperature profile for the Afterbay, there is a choice of calibrating the model to match the temperature profiles observed at the upstream section or to match the temperature profiles of the downstream section, through which the outflow temperatures can be predicted and checked against the temperatures of the outlet station.

Because the primary purpose of the temperature model is to predict the temperatures of the Feather River, we decided to calibrate the model so that it can make a better prediction of temperatures of water releases from Thermalito Afterbay to the Feather River. Since the water is expected to gain heat from the upstream section to the downstream section of the Afterbay, the simulated temperature profiles are expected to be warmer than the temperature profiles measured at the north and south monitoring stations.

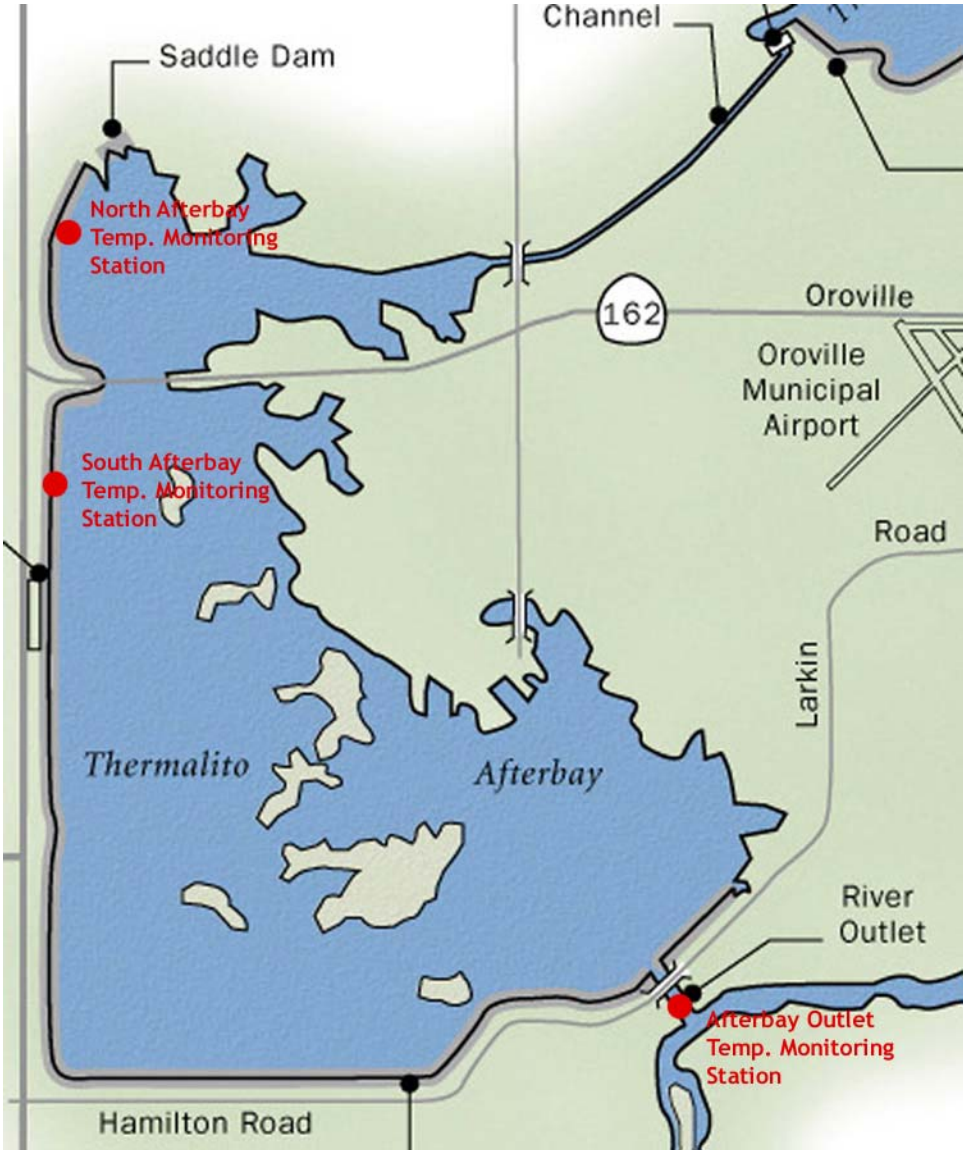


Figure 41 Location Map of Temperature Monitoring Stations in Thermalito Afterbay

Figures 42 to 45 compare the simulated and observed temperature profiles for 4/2/02, 4/24/02, 5/23/02, and 6/17/02 respectively. As shown there is a warming trend of temperature profiles from the north to south monitoring stations. When this trend is projected to the downstream section, the expected temperature profiles fit the simulated temperature profiles.

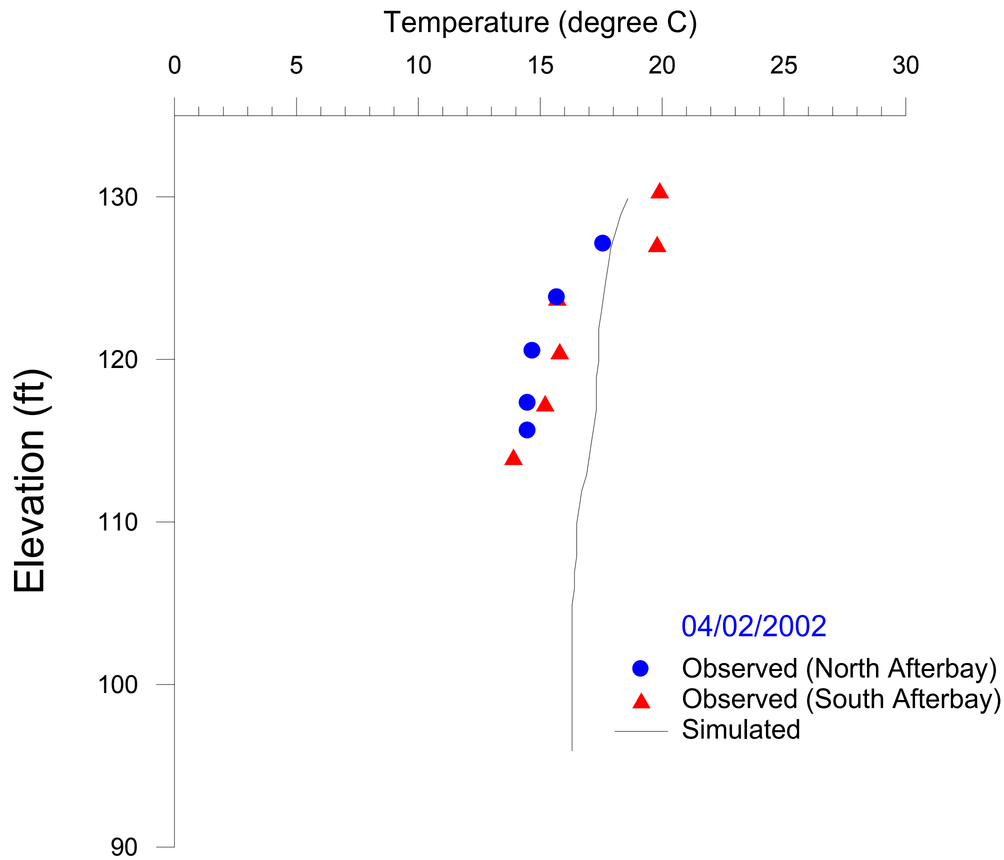


Figure 42 Simulated and Observed Temperature Profile of Thermalito Afterbay for April 2, 2002

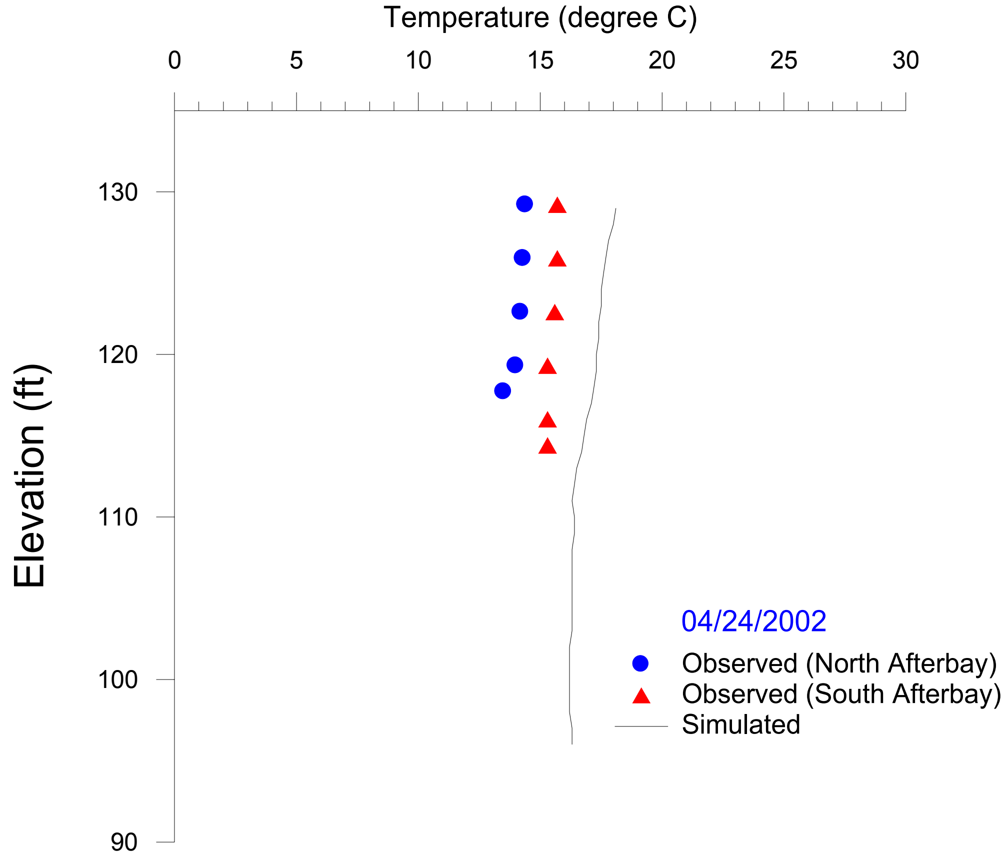


Figure 43 Simulated and Observed Temperature Profile of Thermalito Afterbay for April 24, 2002

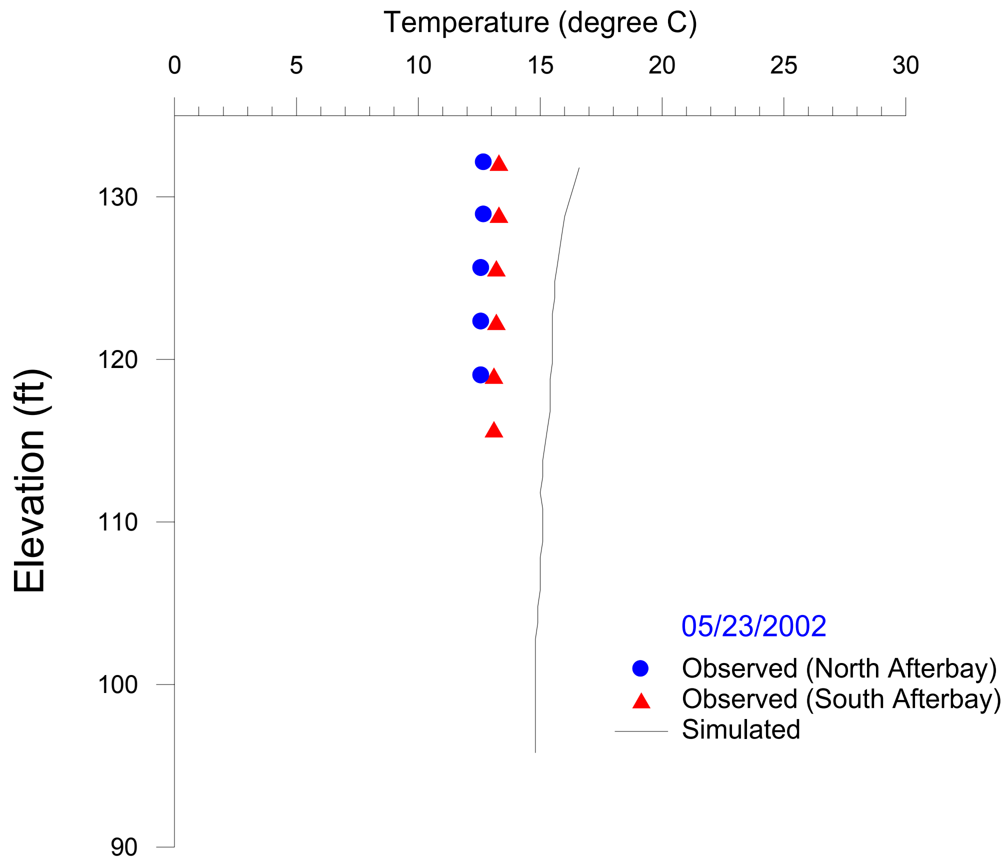


Figure 44 Simulated and Observed Temperature Profile of Thermalito Afterbay for May 23, 2002

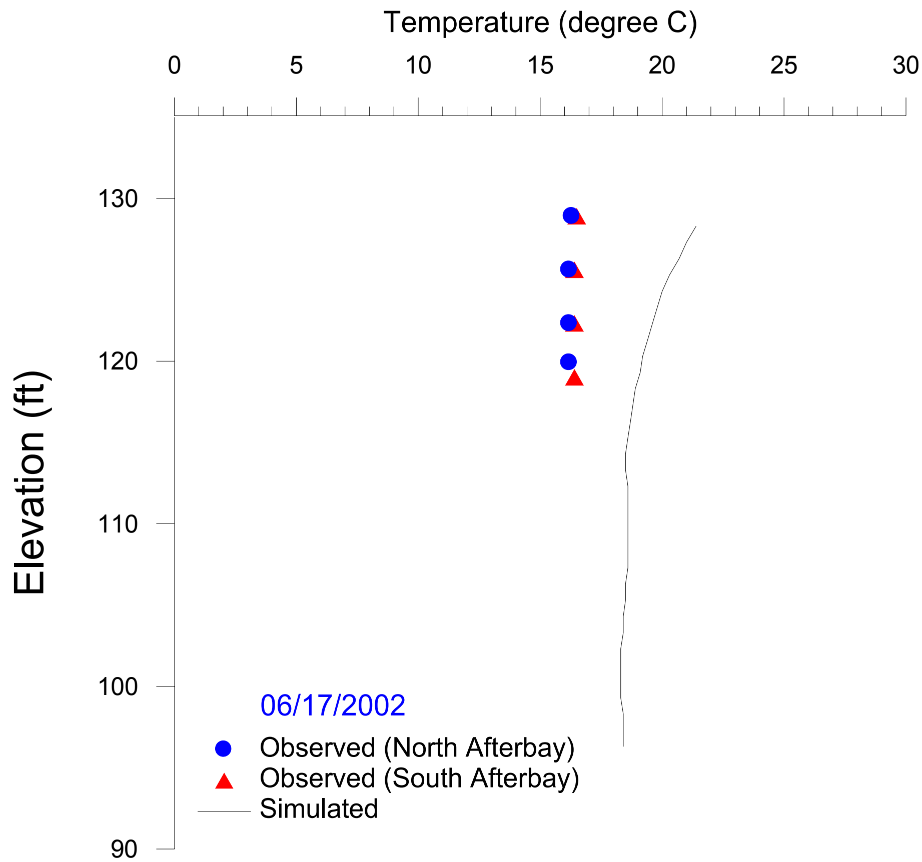


Figure 45 Simulated and Observed Temperature Profile of Thermalito Afterbay for June 17, 2002

Figure 46 compares the simulated and observed outlet temperatures of Thermalito Afterbay. The match was reasonably good. Therefore, the 1D temperature model can predict not only the temperature profiles of the Afterbay but also the outlet temperatures, which are most important to the prediction of temperatures for the Feather River.

Figure 46 also shows the inflow temperatures simulated by the model for reservoir releases from Thermalito Forebay to Thermalito Afterbay. According to the model simulation, the water of Thermalito Afterbay gains approximately six to seven degrees Celsius from the Thermalito Powerplant to Thermalito Afterbay outlet.

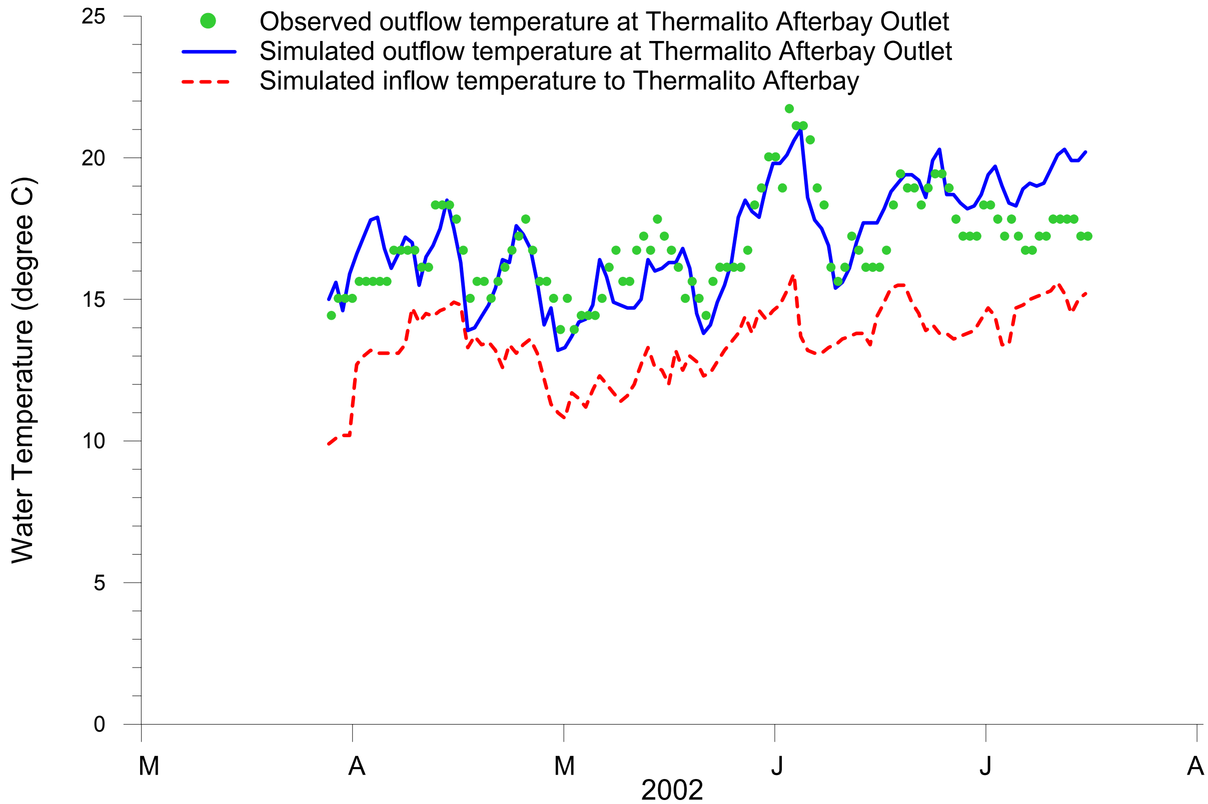


Figure 46 Simulated and Observed Temperatures of Outflows from Thermalito Afterbay

TEMPERATURES OF IRRIGATION DIVERSIONS

DWR has indicated that it is important to be able to predict temperatures of irrigation diversions from Thermalito Afterbay. Two methods can be used. One is to develop an empirical correlation between the diversion temperatures and the Thermalito Afterbay outlet temperatures. The relationship can then be used to calculate the diversion temperature as a function of the simulated outlet temperatures.

The other method is to divide the Afterbay into multiple segments. For each irrigation diversion, there will be a lake segment for it to withdraw water. The depth capacity and depth area curves for each lake segment will be used for setting up the model to simulate Thermalito Afterbay as a series of stratified reservoirs. To develop those curves, however, DWR needs to conduct a new bathymetric survey from which the segmentation can be made. At the present time, DWR only has one set of curves for the entire Thermalito Afterbay.

FUTURE WORK

Work is proceeding on the temperature modeling of the Feather River. After that, we will work on model integration.